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THESIS

OPTIMALLY SCHEDULING EA-6B DEPOT MAINTENANCE AND AIRCRAFT MODIFICATION KIT PROCUREMENT

by

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September 2000

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The Department of the Navy maintains a fleet of 124 EA-6B aircraft, the only tactical electronic warfare aircraft in the Department of Defense inventory. Already 30 years old and not to be retired until 2015, the EA-6B requires depot maintenance services to remain combat ready. EA-6B aircraft undergo standard depot level maintenance (SDLM) about every eight years. In addition to SDLM, depots must complete 72 wing center section replacement services and over 175 major aircraft modification services by 2010. Navy regulations govern when each EA-6B is eligible for each service; these rules are flexible enough to allow more induction schedules than can be evaluated manually in a reasonable amount of time. Because each service keeps an aircraft at the depot for six to 14 months and performing multiple services together requires less time than performing services independently, services should be combined whenever possible. This thesis introduces DMAAP (Depot Maintenance And Acquisition Planner); a prototypic optimization based decision support tool to assist in scheduling EA-6B depot level maintenance services and major aircraft modification kit acquisition. DMAAP produces a Master Plan (induction schedule) providing a monthly schedule for the first six years, a yearly schedule out to 2013 and yearly major aircraft modification kit acquisition levels out to 2010. We compare DMAAP Master Plans obtained using alternate depot induction policies to demonstrate DMAAP's ability and show how yearly depot workloads and yearly operational aircraft vary under alternate policies.

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OPTIMALLY SCHEDULING EA-6B DEPOT MAINTENANCE AND AIRCRAFT MODIFICATION KIT PROCUREMENT

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ABSTRACT

The Department of the Navy maintains a fleet of 124 EA-6B aircraft, the only tactical electronic warfare aircraft in the Department of Defense inventory. Already 30 years old and not to be retired until 2015, the EA-6B requires depot maintenance services to remain combat ready. EA-6B aircraft undergo standard depot level maintenance (SDLM) about every eight years. In addition to SDLM, depots must complete 72 wing center section replacement services and over 175 major aircraft modification services by 2010. Navy regulations govern when each EA-6B is eligible for each service; these rules are flexible enough to allow more induction schedules than can be evaluated manually in a reasonable amount of time. Because each service keeps an aircraft at the depot for six to 14 months and performing multiple services together requires less time than performing services independently, services should be combined whenever possible.

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DISCLAIMER

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASPA	Aircraft Service Period Adjustment
BAA	Backup Aircraft Authorization
BAI	Backup Aircraft Inventory
Block 82	Improved Capability II, version 82
Block 89	Improved Capability II, version 89
Block 89A	Improved Capability II, version 89A
Buno	Department of the Navy aircraft bureau number
COMVAQWINGPAC	Commander Electronic Combat Wing, U.S. Pacific Fleet
CPLEX	Commercial linear program solver software
DMAAP	Depot Maintenance And Acquistion Planner
EA-6B	Prowler, U.S. Navy electronic warfare aircraft
EDMOM	EA-6B Depot Maintenance Optimization Model
FLE	Fatique Life Expenditure
FY	Fiscal Year
FYDP	Future Years Defense Plan
G	Gravitaional acceleration force
GAMS	General Algebraic Modeling System
H-60	Seahawk, U.S. Navy multi-mission helicopter
ICAP-II	Imporoved Capability II
ICAP-III	Imporoved Capability III
ILP	Integer Linear Program
IMC	Integrated Maintenance Concept
M1A1	U.S. Army and Marine Corp main battle tank
NAVAIR	Naval Air Systems Command
OAG	Operational Advisory Group
OPNAV	Office of the Chief of Naval Operations
PAA	Primary Aircraft Authorization
PAI	Primary Aircraft Inventory
PDAA	Primary Development/Test Aircraft Authorization
PDAI	Primary Development/Test Aircraft Inventory
PMAA	Primary Mission Aircraft Authorization
PMAI	Primary Mission Aircraft Inventory
PTAA	Primary Training Aircraft Authorization
PTAI	Primary Training Aircraft Inventory
PED	Period End Date
PMA-234	EA-6B Program Management Office
SDLM	Standard Depot Level Maintenance
SDLM1	First SDLM service
SDLM2	Second SDLM service
T-7050	Type 7050 Aluminum
T-7079	Type 7079 Aluminum
WCS	Wing Center Section
89A	Block 89 to Block 89A modification service
8289A	Block 82 to Block 89A modification service

EXECUTIVE SUMMARY

The Department of the Navy maintains a fleet of 124 EA-6B aircraft, the only tactical electronic warfare aircraft in the Department of Defense inventory. The EA-6B protects U.S. and allied aircraft from potentially hostile anti-air defense systems. Today, the EA-6B remains one of the oldest yet most sought after aircraft in the world; its presence is required for all contingency operations involving military aircraft. Operations such as those in Iraq, Bosnia and Kosovo, in addition to scheduled deployments and training, require 104 operational aircraft.

Nearly 30 years old, the EA-6B requires extensive depot maintenance services to remain combat ready until its retirement in 2015. Current depot services include Standard Depot Level Maintenance (SDLM), Wing Center Section (WCS) replacement and major aircraft modifications. SDLM maintains or restores aircraft to a material condition suitable for fleet operations. EA-6B aircraft undergo SDLM approximately every eight years; over the next fifteen years depots must complete 174 SDLM services. Due to high tasking and age, approximately 72 aircraft are projected to exceed maximum wing fatigue life limits and therefore requiring WCS services. In order to maintain superior combat capabilities, 175 major aircraft modifications must be completed by 2010. Time to complete these services ranges from six to 14 months, total service time is greatly reduced by combining services.

Aircraft inventory management is a primary concern of the EA-6B program office. Maintaining an EA-6B inventory with an adequate number of combat ready aircraft capable of supporting today's numerous operational contingencies requires efficient scheduling of depot services.

Navy regulations limit the periods aircraft are available for SDLM making the scheduling of depot services a complicated process requiring days to manually develop a single schedule. Combining services provides a powerful tool to manage aircraft inventory; however, the number of possible service combinations allows more schedules than can be manually created in an acceptable amount of time.

This thesis introduces DMAAP (Depot Maintenance And Acquisition Planner); a prototypic optimization based decision support tool to assist in scheduling EA-6B depot

level maintenance services. Additionally, DMAAP recommends procurement schedules for major aircraft modification kits. By evaluating possible service combinations, DMAAP quickly produces a Master Plan (depot induction schedule) minimizing total time to complete required services while satisfying several constraints. The Master Plan provides a monthly depot induction schedule for the first six years, a yearly induction schedule out to 2013 and recommends yearly acquisition levels for major modification kits out to 2010. By combining SDLM and WCS services, DMAAP creates a Master Plan completing 435 required services in 269 inductions totaling 2,889 months. By comparison, when we allow the combination of all services, the Master Plan recommends 251 inductions totaling 2,799 months, a decrease of 6.5 percent and 3.1 percent respectively. While the second option reduces overall time to complete services, it also increases (by 20 percent) the time that the number of operational aircraft falls below required levels.

With no replacement aircraft due to arrive in the next ten years, it is imperative that the EA-6B fleet be kept on the cutting edge with the installation of WCS, where needed, and major aircraft modification kits. Modifying all EA-6B aircraft in a timely manner with little impact on the highly tasked fleet is a major concern. By adopting DMAAP to produce a Master Plan, EA-6B program managers acquire the capability to effectively plan and manage the services required to keep the only tactical electronic warfare aircraft at the forefront for another 15 years.

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I. INTRODUCTION

The Department of the Navy maintains a fleet of 124 EA-6B Prowler electronic warfare aircraft (Figure 1). Sixteen U.S. Navy and four U.S. Marine Corps aviation squadrons operate the EA-6B worldwide. Introduced in 1972, the EA-6B is currently the only tactical electronic warfare aircraft in the Department of Defense inventory. Nearly 30 years old, the EA-6B fleet requires depot level maintenance *services* that maintain aircraft material condition and provide *major aircraft modifications.* Depot level maintenance involves large-scale disassembly of the aircraft requiring it to be *inducted* to a specialized depot facility. The Naval Aviation Project Management Office 234 (PMA-234), located at Pautuxent River Naval Air Station, Maryland, schedules and contracts EA-6B depot level maintenance. This thesis introduces DMAAP (Depot Maintenance And Acquisition Planner); a prototypic optimization based decision support tool to assist PMA-234 schedule EA-6B depot level maintenance. In addition to scheduling EA-6B depot level maintenance services, DMAAP can also recommend procurement schedules for major aircraft modification *kits.* A reformulation of the EA-6B Depot Maintenance Optimization Model (EDMOM [Meeks 1999]) provides the basis for DMAAP's Integer Linear Program (ILP).

A. BACKGROUND

Today the EA-6B fleet consists of aircraft that range from 30 years old with more than 10,000 flight hours to as new as eight years with only 1,400 flight hours. In 1996, the Secretary of Defense conducted a "Roles and Missions Bottom-up Review" tasking the Department of the Navy to support all Department of Defense tactical electronic warfare jamming missions [Naval Air Systems Command (NAVAIR) 1997, Nye 2000]. As a result, today the EA-6B is the only tactical aircraft capable of providing electronic warfare support for contingency operations around the globe. These operations include supporting national security strategy in areas such as Iraq, Bosnia, and Kosovo.

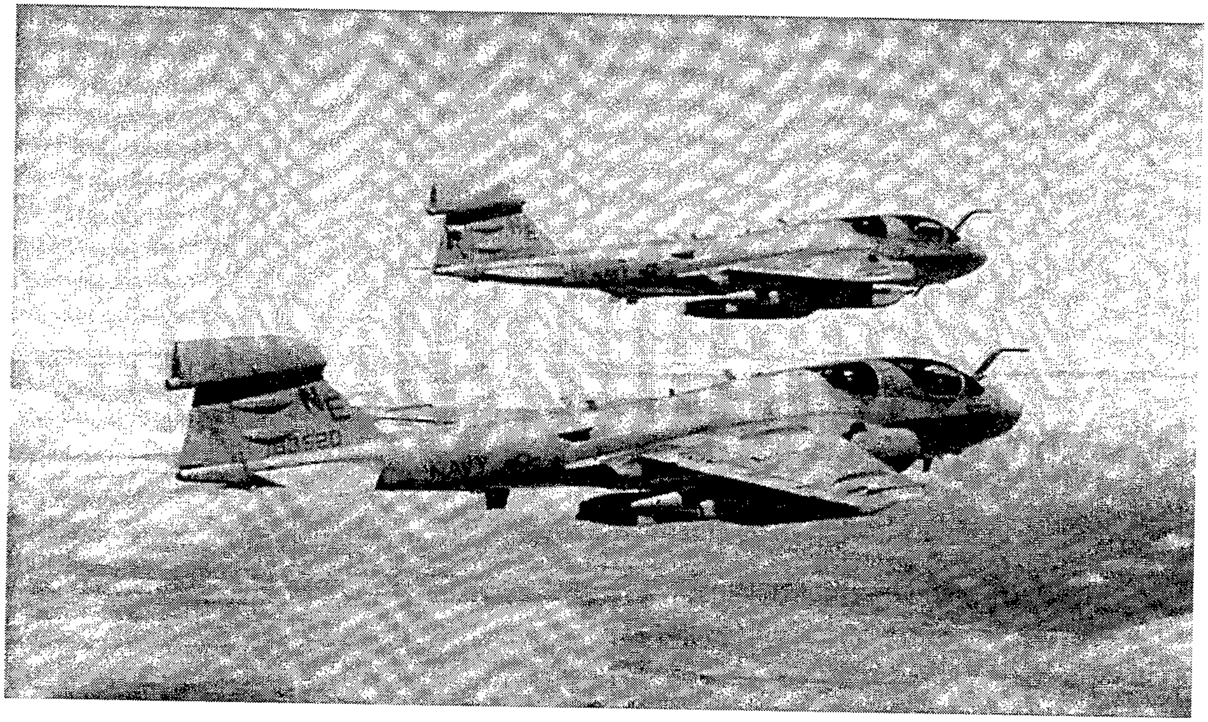

Figure 1. The EA-6B Prowler, Airborne Electronic Jamming Aircraft. The EA-6B protects U.S. and allied aircraft from potentially hostile anti-air defense systems around the globe. The fleet, consisting of aircraft from eight to 30 years old, requires depot level maintenance services providing material condition upkeep and major aircraft modifications. This thesis provides a prototypic optimization based decision support tool, Depot Maintenance and Acquisition Planner (DMAAP), to assist the EA-6B program office (PMA-234) schedule depot level maintenance services. [Photo: SEMCOR 2000]

B. MANAGEMENT OF THE NAVAL AIRCRAFT INVENTORY

The Office of the Chief of Naval Operations (OPNAV) Instruction 5442.8 defines the terms used to manage naval aircraft inventories. Below we provide the terms that regulate how PMA-234 schedules EA-6B depot level maintenance.

OPNAV [1995] defines *Authorization* as a requirement term based on operational tasking and *Inventory* as a term corresponding to the number of aircraft assigned to meet requirements (authorizations). *Primary Aircraft Authorization* (PAA) defines the number of aircraft required to meet all the Department of the Navy's operational tasking; it changes only with changes to long-term operational tasking. *Primary Aircraft Inventory*

(PAI) defines the number of operational aircraft available to meet PAA levels (see Figure 2). *Backup Aircraft Authorization* (BAA) allows for aircraft levels greater than PAA in order to permit scheduled maintenance and aircraft modifications without reducing the number of aircraft available for operational missions. *Backup Aircraft Inventory* is the number of aircraft above PAA levels. *Reconstitution Reserve* is the inventory of aircraft placed in long-term or *mothballed* storage for use in the event of a large-scale mobilization of the U.S. armed forces. PAA plus BAA defines the total number of aircraft required to ensure adequate coverage of all operational tasking.

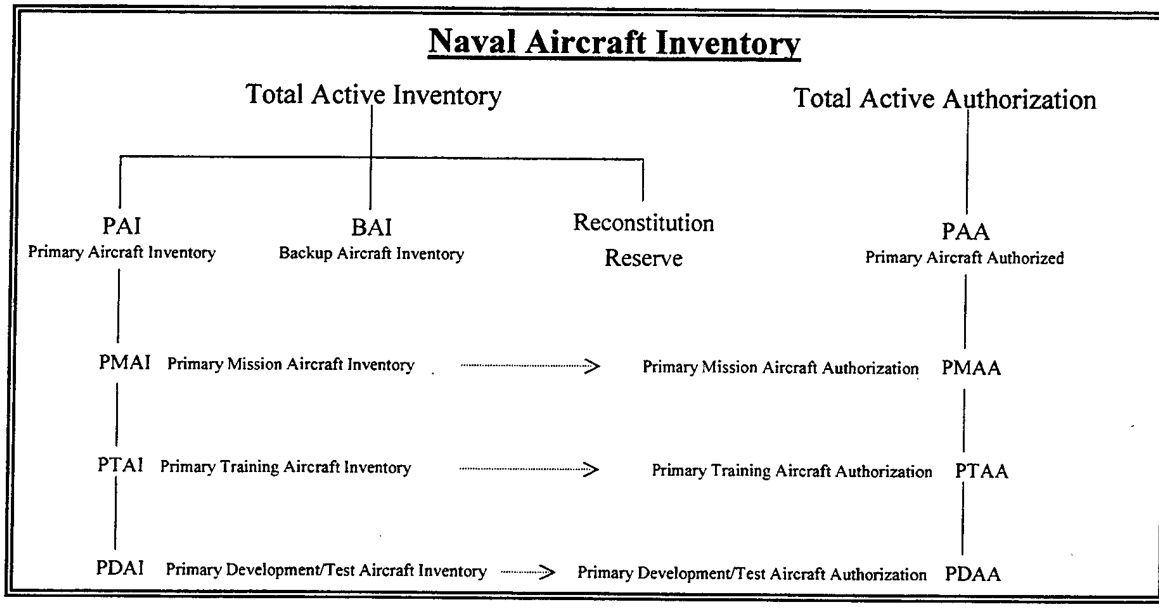

Figure 2. Naval Aircraft Inventory Assignment Chart. Of the 170 EA-6Bs manufactured, 124 still exist. Operational tasking requires 104 aircraft to support operational requirements, defined as Primary Aircraft Authorized (PAA). PAA consists of aircraft authorized for fleet operations (PMAA), pilot training (PTAA) and aircraft/weapon system developmental testing (PDAA). The Primary Aircraft Inventory (PAI) consists of aircraft assigned to support PAA segregated into sub-inventories: aircraft assigned to fleet operations (PMAI), pilot training (PTAI) and developmental testing (PDAI). Aircraft not assigned to one of these three inventories are assigned to the Backup Inventory (BAI) or the Reconstitution Reserve. BAI aircraft are available for scheduled depot level maintenance. Reconstitution Reserve consists of aircraft in long-term mothballed storage for use in the event of a large-scale mobilization of the U.S. armed forces. Current tasking has stretched the inventory to its limits; in 1997 all Reconstitution Reserve aircraft were placed in a modification line in order to reenter the PAI [Nye 1999]. [After OPNAV 1995]

C. DEPOT LEVEL MAINTENANCE SERVICES

Inducting naval aircraft for depot maintenance requires physically locating the aircraft at one of two depots that are certified to conduct maintenance on EA-6B aircraft. Depot induction removes the aircraft from PAI for up to 16 months. *Standard Depot Level Maintenance* and *Wing Center Section* replacement extend airframe service life while *major aircraft modifications (upgrades)* keep the EA-6B's combat capabilities on the cutting edge. WCS and major aircraft modifications require delivery of independent contractor supplied components defined as *kits*.

1. Standard Depot Level Maintenance Service

Standard Depot Level Maintenance (SDLM) [NAVAIR 1998]:

> SDLM is expected to restore aircraft, subjected to this process, to a condition which can be maintained at Organizational (squadron) or Intermediate levels to ensure a high level of operational availability for the duration of the designed service period and to provide interim support during total service life. These requirements include but are not limited to:
>
> a. A thorough and comprehensive inspection of selected aircraft structures, systems and components by appropriate methods, with defect correction, preventative maintenance and modification requirements to ensure serviceability of affected items.
>
> b. Replacement of depot level time-change components that will exceed the specified replacement intervals prior to the next scheduled SDLM.
>
> c. Compliance with all outstanding technical directives, with the exception of specified deviations.

Upon completion of SDLM, aircraft obtain a *Period End Date* (PED); arrival of the PED requires performing an *Aircraft Service Period Adjustment* (ASPA) inspection; a periodic inspection process used to evaluate the material condition of each aircraft and determine if it requires SDLM. Passing ASPA extends the PED one-year; otherwise the aircraft must receive SDLM within 90 days or be placed into storage [NAVAIR 1991].

2. Wing Center Section Replacement Service

The EA-6B fleet has flown an average of 5,665 hours, 37 aircraft (30% of the fleet) have flown over 7,000 hours on wings with an expected service life of only 8,000 hours [SEMCOR 1999]. Squadron level maintenance personnel install replacement outer

and inner wing panels but only depots possess the capability to disassemble the airframe for Wing Center Section (WCS) installation (see Figure 3). *Fatigue Life Expended* (FLE) determines when a WCS must be replaced, it is a direct function of the number and intensity of gravitational accelerations, better known as "G forces" applied to an aircraft. WCS replacement usually occurs after an aircraft passes 95 percent FLE, but the WCS *must* be replaced upon reaching 100 percent FLE [Nye 1999]. PMA-234 schedules aircraft for WCS replacement as well as procuring WCS kits from the manufacturer. It is anticipated that 80 aircraft will receive WCS replacement services over the next eight years [NAVAIR 1999a].

The Commander Electronic Attack Wing Pacific (COMVAQWINGPAC), who controls all Navy EA-6B aircraft, implemented the Fatigue Life Expenditure Management Program in June 1997 in an attempt to preserve the EA-6B's wing service life [COMVAQWINGPAC 1997]. This program requires training flight "G" levels be kept below specified maximums based on current aircraft FLE. These restrictions apply only to Navy aircraft, Marine Corps squadrons do not participate in this program and therefore Marine EA-6Bs suffer higher FLE burn rates. For example, a Marine squadron operating an aircraft with a T-7050 wing has a projected 95 to 100 percent FLE operating window of approximately 12 months. (There are two types of wings in the EA-6B inventory, the older T-7079, which is strong but susceptible to corrosion cracks, and the newer T-7050, which is corrosion resistant but weaker.) A Navy squadron operating the same aircraft under the FLE Management Program would have an operating window of approximately 60 months before the aircraft reaches 100 percent FLE and is subsequently grounded. [SEMCOR 1999]

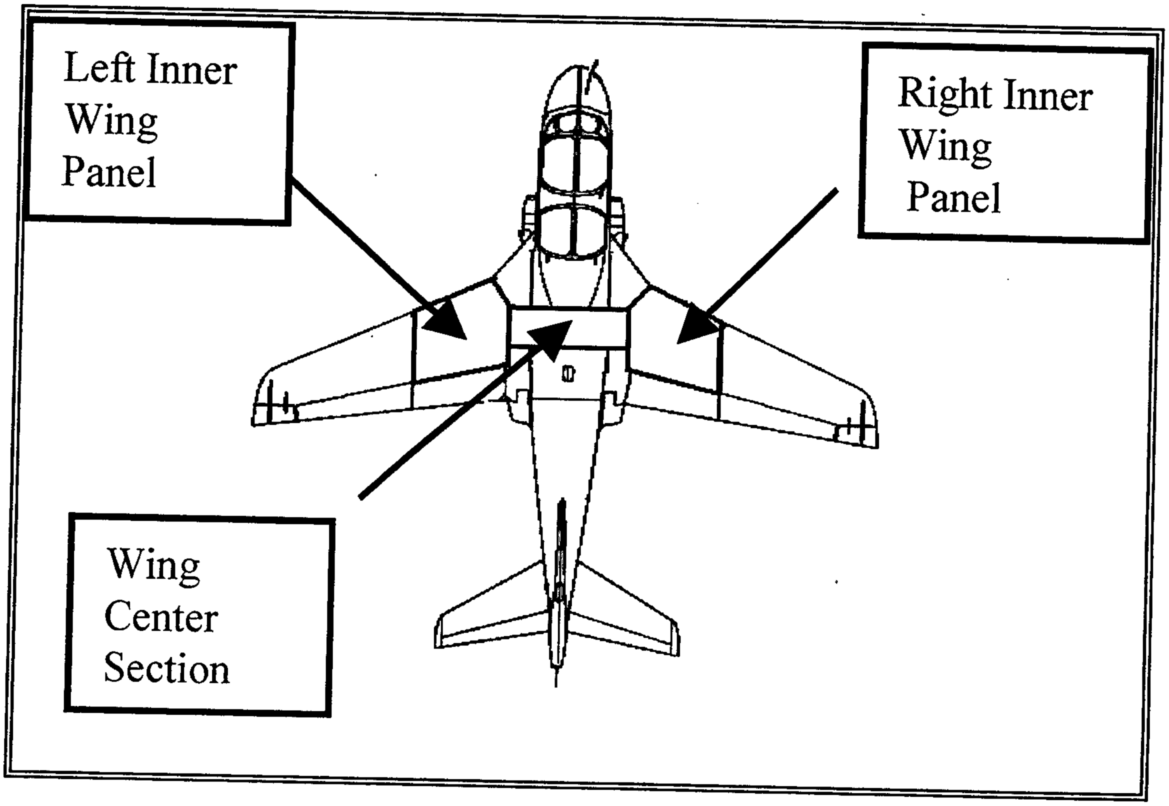

Figure 3. **Top view of an EA-6B.** The EA-6B's Wing Center Section (WCS) must be replaced when wing life reaches 100 percent Fatigue Life Expended (FLE). The Prowler fleet has flown an average of 5,665 hours on wings with an expected service life of 8,000 hours [SEMCOR 1999]. As a result, it is anticipated that 80 aircraft will receive WCS replacement over the next eight years. WCS services require disassembly of the aircraft at a depot, a lengthy process requiring up to 12 months to complete. DMAAP's Integer Linear Program (ILP) creates a depot induction schedule for WCS installation and other depot services. [Figure: NAVAIR 1999b]

3. Major Aircraft Modification Services

In addition to material condition upkeep, depots perform major aircraft modification services that upgrade an aircraft's combat capability (see Figure 4). The heart of the EA-6B is its electronic warfare avionics suite; modified numerous times throughout the years to incorporate new technologies and avionics capabilities. *Improved Capability II* (ICAP-II) is the current version, of which there are three configurations or *blocks* installed in fleet aircraft known as *block 82, 89, and 89A*.

Two EA-6B modification programs are underway with an additional program under development. The *8289A* modification converts block 82 aircraft to 89A, *89A* modification converts block 89 aircraft to 89A and all 89A aircraft will eventually be modified to *Improved Capability III (ICAP-III)*. Currently under development, ICAP-III is a state of the art receiver antenna, cockpit and communications upgrade and the last planned major EA-6B modification. Two ICAP-III prototype systems will be installed in EA-6B aircraft, one in late 2000 and the other in early 2001.

In October 1999 PMA-234 prepared the "EA-6B Modification Management Plan" for the 15th EA-6B Operational Advisory Group (OAG) (see Figure 5) [NAVAIR 1999b]. As the ICAP-III system can only be installed on aircraft configured with block 89A hardware, the plan outlines the process of modifying all Prowler aircraft to block 89A status or consecutively installing 89A and ICAP-III in a single induction. At the time of the 15th OAG about half the fleet was configured as block 82, the other half as 89, and a handful of aircraft had recently been modified to 89A status. PMA-234's Modification Management Plan calls for the modification of all block 82 aircraft and approximately 41 block 89 aircraft to block 89A status by the end of fiscal year 2004. Remaining block 89 aircraft will receive 89A modifications in conjunction with ICAP-III installations. It is anticipated that ICAP-III will enter production in fiscal year 2004.

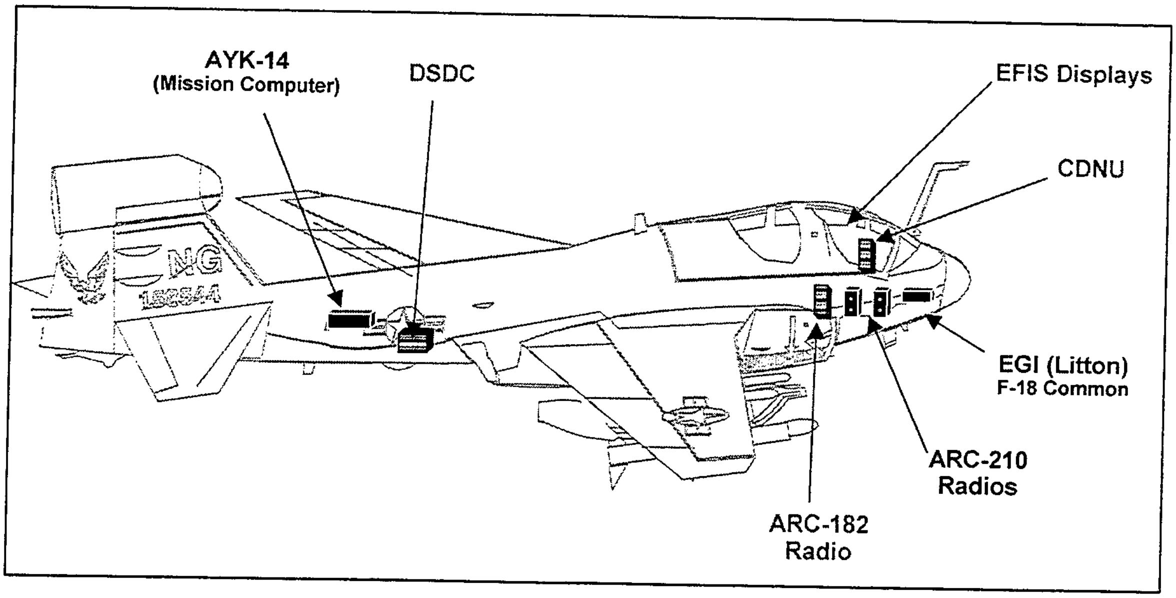

Figure 4. Diagram of block 89A Major Modification Kit installation. The EA-6B airframe has undergone numerous modifications, the latest being the Improved Capability II (ICAP-II). There are three blocks in the ICAP-II family, 82, 89 and 89A. Improved Capability III (ICAP-III) is the next generation modification, under development, projected for production in fiscal year 2004. [From NAVAIR 1999b]

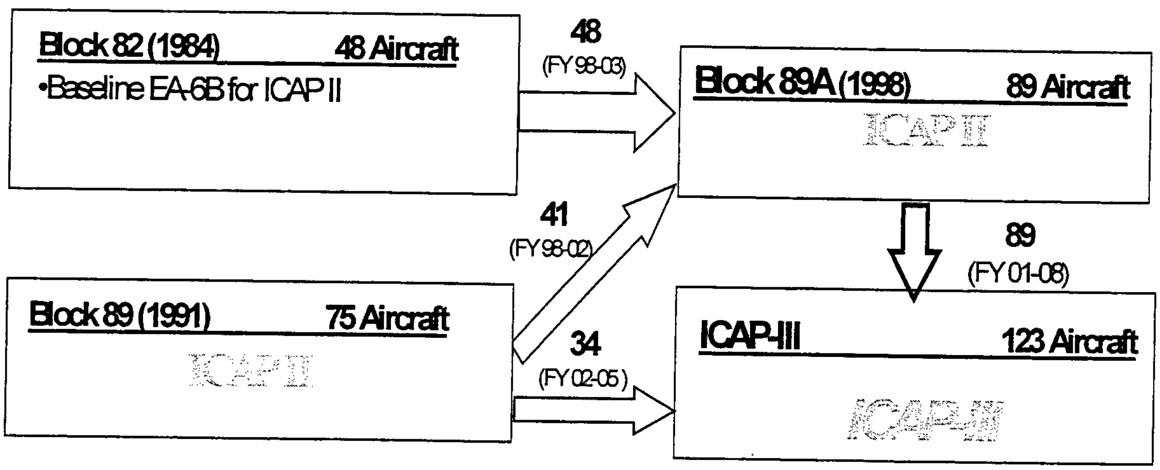

Figure 5. PMA-234's Major Modification Management Plan. This diagram depicts the EA-6B fleet's major modification status as of October 1999. PMA-234 plans to modify all aircraft to ICAP-III by the end of fiscal year 2010, but ICAP-III can only be installed on block 89A aircraft. The arrows depict all feasible modification kit installation sequences with proposed numbers of aircraft and execution dates. [After NAVAIR 1999b]

D. EA-6B INVENTORY STATUS

With continual military commitments around the globe, operational tasking for the EA-6B fleet has never been higher. As a result of the 1996 Bottom UP Review, OPNAV aircraft inventory managers increased EA-6B PAA from 80 aircraft to 104. That same year a depot level *modification line* began work to update all mothballed aircraft to the minimum configuration required by the fleet; we call Reconstitution Reserve aircraft returned to the fleet from this modification line *refurbished aircraft*. Today all EA-6B aircraft are either in a PAI status assigned to an active unit or BAI status receiving required maintenance services or desired modifications. There are no aircraft left in Reconstitution Reserve status that would be available to cope with any further increase in tasking. Every Prowler airframe is needed to provide theater commanders with combat capable electronic warfare aircraft.

The 14th EA-6B OAG recommended a policy of "combining depot level services whenever feasible, to achieve a PAI of 104 aircraft as soon as possible" [COMVAQWINGPAC 1998]. As a result of this policy, PAI rapidly increased to 102 aircraft as the last refurbished aircraft was delivered in August of 2000. This rapid return of refurbished aircraft into the fleet creates a nearly simultaneous requirement to provide these aircraft future SDLM services. The *bow-wave* of refurbished aircraft requiring SDLM has the potential to drop PAI well below 104 in future years.

Even with the delivery of all refurbished aircraft, there is still a requirement for PMA-234 to schedule SDLM, WCS replacement and major aircraft modifications in order to provide a fleet of aircraft able to fill operational requirements until the end of fiscal year 2015. It is hoped that a follow-on jamming aircraft will begin operational service sometime in fiscal year 2012, although this aircraft is only in the concept exploration phase [Marine Corps Times 2000].

Navy regulations prohibit scheduling major modification services for aircraft within the last five years of the fleet's service life. The EA-6B phase-out should be complete by the end 2015; therefore all major modifications must be complete by the end of fiscal year 2010.

E. FUTURE YEARS DEFENSE PLAN BUDGET PROCESS

The *Future Years Defense Plan* (FYDP) is a six-year planning horizon that serves as the basis of the Department of Defense's Planning, Programming, and Budgeting System [Schmoll 1996]. The Department of Defense's fiscal year runs from October 1st to September 30th. Within the FYDP, the military identifies needs and programs for resources; Congress then provides the budget appropriations. The FYDP process provides funding for all depot level maintenance services, WCS kit and major modification kit procurement.

Each year Congress Authorizes and Appropriates funding for the first year and begins debates on the second year of the current FYDP, known as the Budget Years. A budget receives appropriation for the year it is to be executed (the first year of the FYDP). Once a fiscal year budget has received appropriation, PMA-234 can then write contracts for depot services such as SDLM and major modification kit installations. The third through six years of the FYDP, known as the Out-years, record decisions made during the planning phases on approved programs. For example, a WCS procurement contract entered in fiscal year 2000 delivers WCS kits 27 months later [Nye 2000]. Therefore kit installation depot services should be scheduled in the FYDP to ensure these kits can be installed the same year they are delivered. Approved programs such as ICAP-III reside in the FYDP Out-years in order to ensure timely Congressional appropriation when required by the program manager.

F. CURRENT EA-6B DEPOT MAINTENANCE PLANNING

PMA-234, working with SEMCOR Corporation produces the *Master Plan,* used for depot service planning within the FYDP horizon (see Table 1). The plan displays the projected number of SDLM, WCS installations and major modification kit installations for each fiscal year. Referring to Table 1, columns represent fiscal years; within each column aircraft are listed by their Department of the Navy bureau number (buno), a number assigned to all naval aircraft at the time of original manufacture. The plan lists aircraft requiring SDLM followed by aircraft scheduled for *stand-alone* WCS installation and major modification services. Each row shows aircraft buno, system block

configuration, planned induction date and any planned concurrent modification. The Master Plan only provides detailed information for the first two fiscal years; remaining columns only list the aircraft projected for depot services.

FYDP projections for available SDLM, WCS, 8289A, 89A, and ICAP-III modification kits for each fiscal year provide input for the plan. Order of precedence for depot scheduling is: aircraft that have exceeded 100 percent FLE in a prior year and did not receive WCS service, failed or fifth ASPA inspection aircraft, and aircraft projected to reach 95% FLE. Any aircraft having begun its ASPA cycle is a candidate for an early SDLM if it can be combined with one of the other four services. Any aircraft not scheduled to deploy overseas in the next 18 months is eligible to receive WCS and major modification kits scheduled for delivery and not allocated to the above inductions. Aircraft considered for inclusion must have a minimum of two years since their last induction. [Tierney 2000]

PMA-234 uses a level loading policy when scheduling SDLM to ensure a balanced flow of work at each of the depot facilities. Currently fifteen is the target number of SDLMs budgeted for each fiscal year. This number is strictly a planning aid to balance the number of SDLMs from year to year in an attempt to reduce the previously mentioned SDLM bow wave anticipated in fiscal years 2005, 2006 and 2007.

G. PROGRAM FLEXIBILITY

PMA-234 continually updates the Master Plan. Changes most frequently encountered are an ASPA inspection failure before the expected fifth inspection, an aircraft that reaches 95 percent FLE earlier than forecasted, or changes to WCS and major aircraft modification kit delivery schedules. For example, in September 2000, PMA-234 system modification program managers proposed a modified kit delivery plan that increases 8289A and 89A kits in the next few years while reducing the number of initial ICAP-III kits in fiscal years 2004 and 2005. By constructing a draft Master Plan using the new delivery profile, PMA-234 is able to determine how beneficial it is to request a reallocation of funds to support the changes.

Each time PMA-234 receives a change it can take up to a day and a half to manually create a new Master Plan, which provides information for only one option of a multi choice "what if" scenario. Meeks [1999] shortened the scheduling process with the use of an integer linear program favoring concurrent services and early inductions to minimize total time aircraft are removed from PAI. EDMOM is not currently used by PMA-234, as it was a proof-of-concept prototype.

DMAAP provides the capability to satisfy PMA-234's desire to rapidly create a draft Master Plan (Appendix A) in response to an updated inventory status or a proposed change to WCS and major modification kit deliveries. The capability of recommending when to schedule out-year WCS and major modification kit installation is a desirable capability provided by DMAAP. It allows FYDP planning in order to ensure programmed WCS and major modification kit deliveries are dovetailed with programmed depot installation services.

H. PROBLEM STATEMENT

The Department of the Navy requires the services of at least 104 combat capable EA-6B aircraft carrying the most up to date electronic warfare technology available. The aircraft is an aging model of various configurations assigned to units in the Navy and Marine Corps. Recent contingencies throughout the world such as Kosovo, Bosnia, and Iraq have kept a high utilization rate on all EA-6B aircraft. The Navy's challenge is to maintain and upgrade all aircraft to an ICAP-III configuration while holding PAI at or above PAA as much as possible. PMA-234 desires a user friendly, flexible "planning tool" to schedule depot maintenance services for the EA-6B fleet.

I. THESIS CONTRIBUTION AND ORGANIZATION

This thesis introduces DMAAP, a decision support tool for PMA-234, which schedules depot level maintenance services in order to minimize the time (months) EA-6B aircraft are removed from PAI. DMAAP can by used to evaluate scheduling policies

as well as provide recommended WCS and major modification kit installation procurement schedules for the FYDP and beyond.

Organization of the remainder of this thesis is as follows. Chapter II presents an alternative approach to the SDLM process and related research in maintenance scheduling. Chapter III provides DMAAP's assumptions and presents the ILP. Chapter IV details the implementation of the model in the General Algebraic Modeling Language (GAMS), the excel interface developed for model data input and presents policies for scheduling depot services. Chapter V provides an example of using DMAAP to analyze polices presented in Chapter IV and an example of analyzing proposed WCS and major modification kit delivery schedules. Chapter VI provides conclusions and recommendations.

	FY 00						FY 01					
SDLMs	13						10					
WCS	0						5					
82 - 89A	6						12					
89 - 89A	12						8					
ICAP-III	1						1					
SDLM's	BUNO	BLOCK		INDUCTION	MOD	COMMENTS		RWG DATE	BLOCK	5TH ASPA	MOD	COMMENTS
1	158036	82	SA	6/1/00	82-89A		158032		82	7/01	82-89A	AFB 418 / 2
2	158039	89	JX	INDUCTED	SDLM	654	159584		82	10/02	82-89A	AFB 418 / 1
3	156481	89A	JX	3/28/00	SDLM	AFB-418 / 1	160432		82	11/00	82-89A	AFB 418 / 2
4	160434	89A	JX	INDUCTED	SDLM	655/AFB-418	160709	4/01	82	8/04	82-89A	
5	161242	89	JX	INDUCTED	SDLM	653	161347	3/01	89	7/04	89-89A	
6	161774	89	JX	9/1/00	89A/RWG	SU07	163530		89	6/00	89-89A	SSED ASPA
7	161775	89	SA	6/1/00	SDLM		161779		82	10/01	82-89A	
8	161882	82	SA	4/1/00	82-89A		161881		82	5/01	82-89A	
9	163526	89	JX	5/1/00	89-89A	SU06	163031	5/01	82	9/03	82-89A	
10	163887	89	JX	INDUCTED	89-89A	SU04	TBD				82-89A	
11	163888	89	JX	INDUCTED	89-89A	SU02						
12	163889	89	JX	INDUCTED	89-89A	SU03						
13	163891	89	JX	4/1/00	89-89A	SU05						
14												
15												
REWINGS							158650	2/01	82	10/1/00	82-89A	AFB-418 / 2
	159909			6/1/00	ICAP III		158034		82	10/1/00	82-89A	
89A	158035			8/1/00	82-89A	USMC	159583		82	3/1/01	82-89A	
ICAP-III	163045			8/1/00	82-89A	USMC	159585		82	5/1/01	82-89A	
STAND	162936			9/1/00	82-89A	USN	160434		89A	1/1/01	ICAP III	
ALONE	162224			9/1/00	82-89A	USN	163030		89	8/1/01	89-89A	
MODS	163521			6/1/00	89-89A	USN	161120		89	2/1/01	89-89A	
	163398			7/1/00	89-89A	USN	161880		89	5/1/01	89-89A	

Table 1. The EA-6B Depot Induction Master Plan. PMA-234 uses the Master Plan for FYDP scheduling and programming of EA-6B depot maintenance services. The plan displays the projected number of SDLM, WCS installations and major modification kit installations for each fiscal year. For example, the top of the section titled FY00 provides the following information; 13 scheduled SDLM, no WCS, and kit deliveries for six 8289A, 12 8989A and one ICAP-III service. The SDLM block contains 15 numbered rows, the preferred number of SDLMs to perform in a year. Row one shows SDLM induction for aircraft 158036, currently a block 82, on June 1st, 2000 combined with an 8289A modification. Row two shows aircraft 158039, block 89, currently inducted for SDLM. The Stand Alone block at the bottom lists aircraft scheduled for modification services not combined with SDLM. The first row in the stand-alone section lists the induction of aircraft 159909 for ICAP-III service on June 1st 2000. Notice the FY01 section does not have a scheduled induction date for every aircraft. The current process does not provide monthly detail much past the first year of the FYDP. It currently requires approximately one day to manually line out all eligible aircraft and assign induction dates for one year; DMAAP's ILP automates this process allowing creation of a Master Plan in approximately 30 minutes (Appendix A). [After Tierney 2000]

II. RELATED RESEARCH

A. INTEGRATED MAINTENANCE CONCEPT

Integrated Maintenance Concept (IMC) is an attempt to improve Naval Aviation's aircraft availability. It is hoped that by combining squadron, intermediate, and depot level maintenance at a single site, PAI levels can be stabilized close to PAA. Instead of removing aircraft from PAI for induction at depot facilities, depot technicians perform depot services at aircraft operating sites.

The current EA-6B IMC concept is to conduct a field inspection event for each aircraft at its operational site every two years with a depot induction in the eighth year. Once an aircraft enters IMC it adheres to a fixed eight-year cycle receiving a depot service every other year (known simply as Phase 2, 4, 6 and 8). Phase 2, 4, and 6 are two weeks long while Phase 8 is a six-month induction to a depot facility. PMA-234's transition plan calls for eight aircraft to enter IMC in fiscal year 2001 followed by 15 aircraft per phase per year. Aircraft having more than four years since their last SDLM require an additional SDLM before transition to IMC while aircraft with less than four years may enter directly into IMC Phase 2, 4 or 6. Conventional SDLM will eventually be discontinued as IMC Phase 8 services are gradually increased, with the transition complete by 2004. [Leverette 2000]

WCS services cannot be scheduled on a fixed cycle as aircraft burn FLE at varying rates. In addition, the large number of outstanding major aircraft modifications makes it difficult to transfer the EA-6B fleet to a truly fixed IMC cycle. Depots will continue to perform WCS and major aircraft modification services regardless of the type of material upkeep program (SDLM or IMC) adopted by PMA-234. A tool such as DMAAP is beneficial for scheduling WCS and major modification services in either case. Patterson [1997] describes a requirement to *baseline* aircraft for transfer into the IMC maintenance program. This ensures all aircraft entering the program are of similar configuration and of the best material condition. DMAAP's schedule could be used similarly to project when aircraft would be eligible for transfer to IMC.

B. RELATED MAINTENANCE SCHEDULING RESEARCH

The Operations Research literature documents numerous maintenance scheduling optimization models, many dealing with aircraft scheduling. However, most of these existing models do not provide the ability to easily transition between frequently changing input scenarios. Developed to solve a specific problem, at a specified time, using a defined input data set; these models usually offer a one-time solution.

Meeks [1999] developed EDMOM to schedule EA-6B aircraft for SDLM, WCS replacement and major aircraft modification services while minimizing the time aircraft are removed from PAI inventory; his work is the basis of this thesis. EDMOM uses two crucial set derivations to achieve its goals. The model derives a set containing the specific periods each aircraft can receive each type of maintenance service. Intersecting periods the services are offered, with the periods of an aircraft's ASPA inspection cycle and the periods an aircraft is deemed available for SDLM, produces a set of available periods. The model favors completing some services early and thus tends to level-load yearly SDLM inductions. EDMOM is successful at providing an optimized depot schedule but is dependent on estimated future procurement schedules. DMAAP recommends future procurement delivery schedules.

Patterson's optimization model schedules Navy H-60 helicopters for conversion from SDLM to the IMC depot maintenance concept. His definition of "baseline" means that an H-60 helicopter is of "sound structural and material condition" before it is transitioned to IMC [Patterson 1997]. The model's objective is to provide a schedule for base-lining aircraft with as little impact on the fleet as possible. Like DMAAP, the Baseline model minimizes time required to perform depot maintenance while accounting for required upgrades. Unlike DMAAP, which tracks individual aircraft, the Baseline model tracks groups of aircraft assigned to specific squadrons possessing known operational requirements. The Baseline model's objectives are very similar to DMAAP, however two differences between the H-60 and EA-6B communities prevent use of the Baseline model for transitioning EA-6Bs to IMC. First, H-60 aircraft status does not change between depot services, while EA-6B wing FLE changes daily. Individual EA-6B aircraft must be tracked by DMAAP to insure timely WCS inductions for aircraft that

may exceed 100 percent FLE earlier than projected. Second, squadrons in the H-60 community provide small detachments of helicopters for operational deployments allowing Patterson to schedule induction slots to aircraft cohort groups. These groups can then be assigned to squadrons with light deployment schedules. EA-6B squadrons only have four aircraft and deploy as full units, they cannot afford to have more than one aircraft at a time inducted into a depot. Regardless of the material upkeep concept EA-6Bs receive, modification management will benefit from a depot-scheduling model of the type developed in this thesis.

Bargeron [1995] introduces an integer linear program to establish an effective and efficient depot maintenance policy for the Marine Corps M1A1 main battle tank fleet. His model has an underlying network structure that models the location of tanks. Nodes represent possible tank locations, (e.g., units or depots) while the arcs represent maintenance decisions such as keeping a tank at the unit, shipping to the depot or depot inventory. The model minimizes the average time (cost) between depot inductions while satisfying capacity and operational requirements. To avoid tracking individual vehicles, the Tank model uses groups of tanks indexed by location and length of time from the last depot maintenance (defined as age in the model). Again because of the changing status of each Prowler's wing FLE and block configurations, a minimum cost flow model such as the Tank model cannot be used. Additionally the Tank model only considers two tank types that do not change as a result of the single maintenance service provided by a tank depot. In contrast, DMAAP must track the aircraft characteristics that may change after a depot service and recommend different types of maintenance while minimizing the time aircraft are inducted into the depots.

Albright [1998] develops an optimization model using a set partitioning formulation to group preventive maintenance tasks under the IMC concept, while minimizing aircraft out of service time. Although the objectives of Albright's model and DMAAP are similar, Albright's model considers all types of preventative maintenance, performed at all levels of the fleet daily, by a large number of units. Albright's model does not posses the ability to track aircraft either in a SDLM or IMC cycle. This grouping of maintenance actions could prove useful to the EA-6B community once aircraft have entered the IMC cycle.

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III. OPTIMIZATION MODEL DEVELOPMENT

This chapter presents DMAAP's ILP, which provides yearly induction schedules for depot level maintenance services. The ILP minimizes total time aircraft are removed from PAI and penalties in order to conduct required SDLM, WCS, 8289A, 89A and ICAP-III services. By minimizing the time aircraft are removed from PAI, we also minimize the magnitude of the difference of PAA minus PAI over time. The ILP adheres to PMA-234 scheduling policies, FYDP programmed procurement and installations, and configuration requirements.

The ILP tracks each aircraft using its bureau number. The *service* index indicates the type of depot maintenance (see chapter I.C) performed during a scheduled induction and *period* is the measure of time. Indices are also used to count the number of SDLM inductions per fiscal year, define possible combinations of services, and partition periods into fiscal years.

A. MODEL ASSUMPTIONS

Not all aircraft need every depot service. For example, all aircraft are eligible for SDLM but a block 89A aircraft does not require the 8289A service. The aircraft index is used to create indexed sets consisting of aircraft *eligible* for a specific service. Because the EA-6B SDLM cycle is approximately eight years, only aircraft requiring SDLM prior to October 2005 are included in the eligible set for a second SDLM. Because the EA-6B is to be retired in 2015, no SDLM inductions are allowed after the end of fiscal year 2013. Aircraft that have not received a previous WCS service and are projected to reach 95% FLE prior to fiscal year 2010 are included in the WCS eligible set. The 8289A eligible set includes all block 82 aircraft, the 89A eligible set includes all block 89 aircraft, and the ICAP-III eligible set includes all aircraft.

A key aspect of the ILP is the division of time into periods small enough to create a depot induction schedule, but not so small that the model becomes intractable. A *period* equals a month for the six years contained within FYDP, beyond which a *period* is equal to a fiscal year. (No budget planning or programming exists for fiscal years outside

the FYDP; therefore model recommendations on a fiscal year resolution seem adequate.) Using periods of different length allows the model to provide a schedule with greater resolution than the current Master Plan in reasonable solution times.

Option indicates the service or multiple services to be performed during a single induction to a depot facility (see Table 2). Options allow service combinations capable of reducing the time aircraft are removed from PAI. Aircraft may not be *available* for all options containing services they are eligible to receive. For example, all aircraft are eligible for ICAP-III, but the consecutive nature of the block modifications prevents the availability of some options containing the ICAP-III service. ICAP-III can only be installed on block 89A aircraft, therefore a block 82 aircraft cannot be inducted for option number 6 but may be inducted for option 16 (see Table 2).

Every aircraft requires at least one SDLM service defined as *SDLM1*. Aircraft eligible for a second SDLM receive *SDLM2* services. Except SDLM, which occurs at the end of the SDLM/ASPA cycle, aircraft receive each service only once.

Each aircraft's required services must be performed within a specified time window; in other words, aircraft are not *available* in every time period for every service. For example, all aircraft are eligible for SDLM, but this service is only performed between six months prior to and three months after the assigned PED [NAVAIR 1991, OPNAV 1998]. Recall, approaching the PED requires an ASPA inspection to determine whether the PED may be extended by twelve months. Using historical ASPA failure rates PMA-234 assumes that all aircraft pass all ASPA inspections prior to the fifth. In most cases, SDLM induction occurs in lieu of a fifth ASPA inspection [Nye 1999].

The set consisting of periods aircraft are available for SDLM1 is comprised of the nine months around the fifth ASPA as described above. The SDLM cycle consists of a three year Operating Service Period plus the assumed four ASPA extensions. Adding the SDLM cycle to the first and last periods of the SDLM1 available set produces the SDLM2 available set. No aircraft will require more than one SDLM within the FYDP and only a portion of the total aircraft require a SDLM2, which will always occur outside the FYDP. Because model periods outside the FYDP represent fiscal years, the SDLM2 available set consists of at most one period corresponding to the appropriate fiscal year.

Option	Included Services	Months	Option	Included Services	Months
1	SDLM1	10	19	89A, ICAPIII	9
2	SDLM2	10	20	SDLM1, WCS, 8289A	14
3	WCS	10	21	SDLM1, WCS, 89A	14
4	8289A	9	22	SDLM1, WCS, ICAPIII	14
5	89A	6	23	SDLM1, 8289A, ICAPIII	16
6	ICAPIII	6	24	SDLM1, 89A, ICAPIII	14
7	SDLM1, WCS	12	25	SDLM2, WCS, 8289A	14
8	SDLM1, 8289A	13	26	SDLM2, WCS, 89A	14
9	SDLM1, 89A	12	27	SDLM2, WCS, ICAPIII	14
10	SDLM1, ICAPIII	13	28	SDLM2, 8289A,ICAPIII	16
11	SDLM2, WCS	12	29	SDLM2, 89A, ICAPIII	14
12	SDLM2, 8289A	12	30	WCS, 8289A, ICAPIII	10
13	SDLM2, 89A	12	31	WCS, 89A, ICAPIII	10
14	SDLM2, ICAPIII	13	32	SDLM1, WCS, 8289A, ICAPIII	16
15	WCS, 8289A	10	33	SDLM1, WCS, 89A, ICAPIII	14
16	WCS, 89A	10	34	SDLM2, WCS, 8289A, ICAPIII	16
17	WCS, ICAPIII	10	35	SDLM2, WCS, 89A, ICAPIII	14
18	8289A, ICAPIII	9			

Table 2. Table of Possible Depot Maintenance Options. Some services can be conducted concurrently by depot facility. The combination of services into options allows required maintenance to be performed in less total time than consecutive single service inductions. For example, both SDLM1 (option 1) and WCS (option 3) require ten months to complete, but if we concurrently perform the two services (option 7) total time to complete both services is only 12 months. [After Meeks 1999]

Available sets for WCS replacement begin with NAVAIR Industrial Operations Group's projection of the dates each aircraft will reach 95 and 100 percent FLE. The size of the available set is dependent on the service (Navy or Marine) and wing type combination shown in Table 3. Navy aircraft operating under the FLE Management Program [COMVAQWINGPAC 1997] theoretically have a WCS available window exceeding five years, however the ILP limits the set to three years. This is done for two reasons and can be removed at the discretion of the model user. First, over fiscal year 2000 actual FLE burn rates have exceeded projected rates; three aircraft reached 100% FLE earlier than projected. Secondly, training under the FLE Management Program has been deemed unrealistic in preparing for some aspects of combat [Nye 2000]. Upon reaching 100 percent FLE each aircraft is granted a one-time flight to the depot where it is placed in long-term storage awaiting a WCS. It is undesirable to leave an aircraft

grounded for any length of time, so when a WCS becomes available it is usually assigned to a grounded aircraft.

Wing Type	T-7050	T-7079
USN	60	187
USMC	12	22

Table 3. Theoretical Time in months between 95 and 100% FLE. There are two types of wings in the EA-6B inventory, the older T-7079 is strong but susceptible to corrosion cracks, and the newer corrosion resistant but weaker T-7050. The Fatigue Life Expenditure Management Program is the Navy's attempt to preserve the EA-6B's service life [COMVAQWINGPAC 1997]. This program only applies to Navy aircraft. Marine Corps squadrons do not participate in this program and therefore Marine EA-6Bs suffer higher FLE burn rates. Navy aircraft are capped at 36 months to place a realistic upper bound on how long an aircraft should be flown with a WCS exceeding 95% FLE.

Available sets for major aircraft modification services start with the period kits first becoming available and end with the last year in which major aircraft modifications are allowed, as determined by NAVAIR (currently 2010). Modification kits for converting block 82 to 89A and 89 to 89A are in full production, ICAP-III production kits arrive in fiscal year 2004. Due to high maintenance times and peculiar parts support required for block 82 aircraft, PMA-234 plans on modifying all block 82 aircraft by the end of fiscal year 2004.

Budget policies require service components delivered in a specific fiscal year be scheduled for installation in the same year [Nye 2000]. Model constraints enforce this policy within the FYDP, however the ILP recommends installation schedules outside the FYDP as no procurement contracts have been let for those fiscal years. The user can relax this policy constraint if he desires to use the DMAAP's preferred installation schedule. When the installation constraint is relaxed, the ILP allows inductions for kit installation services in years other than the delivery year. This usually happens if the kit installation can be combined with other services at a later date.

Although there are two depot facilities with real workload constraints, for the purpose of DMAAP PMA-234 does not want recommended inductions to a specific

depot or limits on the amount of work each facility can perform. It is our intent, as much as possible, not to constrain the ILP for workload, thus letting it recommend services based on what each aircraft needs and when it needs it. However, early model testing indicates the need for a realistic upper bound on total workload at both depots to counter model end-effects [Walker 1995]. Constraints limit the total amount of work (total maintenance time) started in a fiscal year.

Aircraft loss through attrition is not modeled, although the nature of military operations guarantee this assumption will not hold. In the unfortunate event that an aircraft is lost the DMAAP user can simply remove the specific aircraft bureau number from the data set and runs the ILP.

B. PENALTIES

The objective function contains penalties, calculated as months out-of-service, associated with elastic variables placed in appropriate constraints. This approach provides two benefits; it ensures a feasible solution, while elastic variables provide recommended WCS and major modification service kit procurement levels to preclude future shortfalls.

The first penalty equals the months an aircraft is removed from PAI to perform a recommended option, plus a value equal to the difference between the period the option was recommended and the period the aircraft was first available for that option. For example, if the ILP recommends an aircraft be inducted for WCS five periods after it reaches 95 percent FLE (the first period of its available set) then 10.5 months is charged to the objective function. The penalty consists of the 10 months required to install the WCS (see Table 2) plus a 0.5-month penalty for inducting five months late.

The second penalty is assessed for exceeding the SDLM level-loading target. Constraints count the number of SDLM inductions above the target number for each fiscal year. The penalty is equal to the minimum months to complete a SDLM service for the first recommended SDLM above the target level and gets progressively larger by one month for each extra SDLM. For example, it takes ten months to complete a SDLM (see

Table 2) so the penalty is ten months for the first SDLM above the target level and 11 months for the second.

The third penalty adds 12-months if recommended consecutive inductions for an aircraft violate a defined minimum amount of time set by the user. The restriction on consecutive inductions allows a reasonable return on recently completed depot maintenance services before the aircraft is again removed from PAI.

The last two penalties increase the objective function if WCS or modification components are unavailable for periods coinciding with the ILP's recommended inductions. An aircraft reaching the end of its WCS available period without an available WCS is equivalent to being grounded because of 100 percent FLE. A penalty of 12 months is assessed when an aircraft reaches 100 percent FLE and WCS kits are unavailable. Major aircraft modifications such as 8289A, 89A and ICAP-III, are desired services that can be completed anytime. An aircraft should only be taken out of PAI for a major modification stand-alone option if it is more beneficial than waiting for a later date when services may be combined. There are two cases for enforcing the penalty; the first is for recommending kit installations for periods outside the FYDP. We want the ILP to provide this information and therefore the penalty is set to a value of one, (it simply counts the number of kits that should be made available). There are many ways in which to use a modification kit if it is made available, so the penalty structure inside the FYDP is the average of the difference for a stand-alone service and other options including the service. For example, the average difference in time to complete options containing the 8289A and the stand-alone service is four months, so the penalty for not having a 8289A component available for an eligible aircraft within the FYDP is four.

C. MODEL FORMULATION

This section shows the indices, sets, data, decision variables and mathematical formulation of the model.

Indices:

a	aircraft	(e.g., identified by bureau number);
e	extra SDLMs	(e.g., 1, 2, …, above the target);
o	option	(e.g., Option 1,…, Option 35);
p	period	(e.g., Oct99, Nov99,…, Sep07, FY08,…, FY15);
s	service	(e.g., SDLM, WCS, 8289A, 8989A, ICAPIII) and
y	fiscal year	(e.g., FY00, FY01,…, FY15).

Sets:

$AvailSet_{a,o}$	Periods aircraft *a* available for option *o*;
$EligSet_s$	Aircraft eligible for service *s*;
$FySet_y$	Periods in fiscal year *y*;
$FyDp$	Periods contained in the "Future Years Defense Planning" horizon;
$OutYr$	Periods outside the FYDP;
$OptSet_s$	Options that include service *s*; and
$Year_p$	Year containing period *p*.

Data:

$notInServ_{a,o}$	Months aircraft *a* is not in service in order to receive option *o*. This includes a discounted penalty if aircraft *a* is inducted for a required option *o* in a period after it was initially available for that option (months);

$deliv_{p,s}$	Number of service s components that become available in period p (aircraft);
$indEarly_s$	Maximum number of periods before a service s kit becomes available that an aircraft may be inducted to use the kit (periods);
$minOpTime$	Minimum number of periods between the completion of an option and the successive induction (periods);
$sdlmPenalty_{e,y}$	Discounted penalty for the e[th] SDLM above the targeted number of SDLM inductions in a fiscal year y (months);
$tgtSDLM$	Targeted number of SDLM inductions per fiscal year (aircraft);
$time_o$	Number of months required to perform option o (months);
$buyMore_y$	Penalty for not having kits available in the out-years. Encourages the buy of kits (months); and
$maxWork_y$	Maximum amount of new work that can be added in fiscal year y (months).

Decision Variables:

$INDUCT_{a,o,p}$	One if aircraft a is inducted for option o during period p, zero otherwise (binary);
$MORESDLM_{e,y}$	One if the e[th] SDLM above the targeted number of SDLM inductions is scheduled during fiscal year y, zero otherwise (positive variable);
$VIOMINOP_a$	One if aircraft a violates the minimum number of months between the completion of an induction and the successive induction (positive variable); and
$NOKITS_{s,y}$	Number of kits that should be purchased in fiscal year y (positive variable).

Mathematical Formulation:

Minimize the Objective Function...

$$\sum_{a,o,p} \text{notInServ}_{a,o,p} * \text{INDUCT}_{a,o,p} + \sum_{e,y} \text{sdlmPenalty}_{e,y} * \text{EXTRASDLM}_{e,y} + \sum_{a} \text{minOpTime} * \text{VIOMINOP}_{a}$$
$$+ \sum_{s,y} \text{buyMore}_{y} * \text{NOKIT}_{s,y}$$

Subject to...

(C1) $$\sum_{o \in \text{OptSet}_s} \sum_{p \in \text{AvailSet}_{a,o}} \text{INDUCT}_{a,o,p} = 1 \qquad \forall s \notin \{\text{SDLM2}\}, a \in \text{EligSet}_s$$

(C2) $$\text{INDUCT}_{a,o,p} \leq \sum_{o' \in \text{OptSet}_{\text{"SDLM2"}}} \sum_{p' \in \text{AvailSet}_{a,o'}} \text{INDUCT}_{a,o',p'}$$
$$\forall a \in \text{EligSet}_{\text{"SDLM2"}}, o \in \text{OptSet}_{\text{"SDLM1"}}, p \in \text{FyDp}$$

(C3) $$\sum_{a} \sum_{o \in \text{OptSet}_{\text{"SDLM1"}} \cup \text{OptSet}_{\text{"SDLM2"}}} \sum_{p \in \text{FySet}_y} \text{INDUCT}_{a,o,p} \leq \text{tgtSDLM} + \sum_{e} \text{EXTRASDLM}_{e,y} \qquad \forall y$$

(C4) $$\sum_{a,o \in \text{OptSet}_s} \sum_{p' \leq p} \text{INDUCT}_{a,o,p'} \leq \sum_{p' \leq p + \text{indEarly}_s} \text{deliv}_{p',s} + \sum_{y \in Year_p} \text{NOKIT}_{s,y}$$
$$\forall s \in \{\text{WCS}, \text{8289A}, \text{8989A}, \text{ICAPIII}\}, p \in \text{FyDp}$$

(C5) $$\sum_{a,o \in \text{OptSet}_s} \sum_{y' \leq y} \sum_{p \in \text{FySet}_{y'}} \text{INDUCT}_{a,o,p} \leq \sum_{y' \leq y} \sum_{p \in \text{FySet}_{y'}} \text{deliv}_{p,s} + \text{NOKIT}_{s,y}$$
$$\forall s \in \{\text{WCS}, \text{8289A}, \text{8989A}, \text{ICAPIII}\}, y \in \text{OutYr}$$

(C6) $$\sum_{s} \sum_{a,o \in OptSet_s} \sum_{p \in FySet_y} INDUCT_{a,o,p} * time_o \leq minWork_y \qquad \forall y$$

(C7) $$\sum_{o \in OptSet_s} \sum_{p' \leq p} INDUCT_{a,o,p'} \geq \sum_{o \in OptSet_{"ICAPIII"}} INDUCT_{a,o,p}$$

$$\forall s \in \{8289A, 8989A\}, a \in \{EligSet_s \cap EligSet_{"ICAPIII"}\}, p$$

(C8) $$\sum_{o} \sum_{p' = p - minOpTime - time_o + 1} INDUCT_{a,o,p'} \leq 1 + VIOMINOP_a \qquad \forall a, p$$

(C9) $$INDUCT_{a,o,p} \in \{0,1\} \qquad \forall a, o, p$$

(C10) $$0 \leq MORESDLM_{e,y} \leq 1 \qquad \forall e, y$$

(C11) $$VIOMINOP_a \geq 0 \qquad \forall a$$

(C12) $$NOWCS_y \geq 0 \qquad \forall y$$

(C13) $$NOKITS_{s,y} \geq 0 \qquad \forall s, y$$

When executed the ILP minimizes: time to complete options plus late inductions; the number of extra SDLMs above the target; the number of aircraft with short times between successive inductions; aircraft that are grounded due to unavailable WCS components; and the number of modification kit shortfalls prior to the last allowed installation date. The key decision variable is the binary $INDUCT_{a,o,p}$, which has value one if aircraft *a* is recommended for option *o* in period *p*. The number of variables is kept to a minimum by considering only aircraft that are eligible for an option in the periods that the aircraft is available for the recommended option.

The first objective function term counts total months to perform an option plus a discounted value of the difference between the recommended month and the earliest month available for that service. The second term gauges the number of SDLMs above a yearly target. The third penalizes for each aircraft that violates minimum time between inductions. (Meeks [1999] uses these same three terms.) The forth term penalizes for violating the elastic constraint of a required WCS replacement by 100 percent FLE or not modifying aircraft when available for the service. Penalties are scaled to ensure continuity between periods inside and outside the FYDP.

Constraints (C1) and (C2) ensure every aircraft receives each service. Constraint (C3) counts scheduled SDLM inductions above the yearly target. Constraint (C4) limits the periods that an aircraft can be inducted prior to the delivery of kits for that service. Constraint (C5) ensures the number of inductions for kit installation services (WCS, 8289A. 89A. ICAPIII) in a year is no greater than the number of kits previously delivered or counts the number of outstanding kit installation services after all kits have been exhausted. Constraint (C6) limits the total maintenance months initiated in any fiscal year. This prevents unrealistic workloads caused by model end-effects in the last period of allowed modification services. Constraint (C7) mandates that an aircraft be modified to block 89A prior to receiving an ICAP-III modification. Constraint (C8) enforces a minimum number of months between inductions. Constraint (C9) defines $INDUCT_{a,o,p}$ as a binary variable. Constraint (C10) sets upper and lower limits on $MORESDLM_{e,y}$. Constraints (C11, C12 and C13) define $VIOMINOP_a$, $NOWCS_y$ and $NOKITS_{s,y}$ as non-negative variables.

D. DERIVATION OF AVAILABLE SETS

Available sets contain the periods that each aircraft is available for each option it is eligible to receive. In order to construct available sets the ILP initially creates sets containing the actual periods each aircraft is available for each service. For example if aircraft 158036's fifth ASPA is due January 2003 the periods it is available for SDLM consist of the six months prior to and three months after the ASPA date (as specified in III.A.2) or July 2002 to April 2003. The available set for any option containing SDLM1 is the intersection of the SDLM period set and the period set for each service contained in that option. Meeks [1999] uses additional sets and data to derive $\text{AvailSet}_{a,o}$, which is defined, as the periods aircraft "a" is available to receive option "o". The ILP uses the original set formulation used by EDMOM as defined below

Mathematically $\text{AvailSet}_{a,o}$ is defined as [Meeks 1999]:

$$\text{AvailSet}_{a,o} = \begin{cases} \bigcap\limits_{s \in \text{ServSet}_o} \text{PdSet}_{a,s} \bigcap\limits_{s \in \text{ServSet}_o} \text{OperSet}_s & \forall a,o \mid \{\text{SDLM1}, \text{WCS}\}, \{\text{SDLM2}, \text{WCS}\} \not\subset \text{ServSet}_o, \\ \bigcap\limits_{\substack{s \in \text{ServSet}_o \\ s \neq \text{SDLM1}}} \text{PdSet}_{a,s} \bigcap\limits_{s \in \text{ServSet}_o} \text{OperSet}_s \bigcap \text{ASPA1Set}_a & \forall a,o \mid \{\text{SDLM1}, \text{WCS}\} \subset \text{ServSet}_o \\ \bigcap\limits_{\substack{s \in \text{ServSet}_o \\ s \neq \text{SDLM2}}} \text{PdSet}_{a,s} \bigcap\limits_{s \in \text{ServSet}_o} \text{OperSet}_o \bigcap \text{ASPA2Set}_a & \forall a,o \mid \{\text{SDLM2}, \text{WCS}\} \subset \text{ServSet}_0 \end{cases}$$

Where:

- $\text{PdSet}_{a,s}$ the periods aircraft a is available for service s. For example, the projected periods that an aircraft will be between 95 and 100 percent FLE.
- OperSet_s is the periods that service s is available, the present to September 2015 for SDLM, the present to September 2010 for all other services.
- ASPA1Set and ASPA2Set define the periods an aircraft is in its ASPA inspection cycle for the respective SDLM service.
- ServSet_o is services included in option o.

In order to model the current PMA-234 policy of allowing early SDLM induction if combined with any modification service, we further relax the derivation of available sets containing SDLM service as defined below.

Mathematically $AvailSet_{a,o}$ is redefined as:

$$AvailSet_{a,o} = \begin{Bmatrix} \bigcap_{s \in ServSet_o} PdSet_{a,s} \bigcap_{s \in ServSet_o} OperSet_s & \forall a,o \mid \{SDLM1\},\{SDLM2\} \not\subset ServSet_o, \\ \bigcap_{\substack{s \in ServSet_o \\ s \neq SDLM1}} PdSet_{a,s} \bigcap_{s \in ServSet_o} OperSet_s \bigcap ASPA1Set_a & \forall a,o \mid \{SDLM1\} \subset ServSet_o \\ \bigcap_{\substack{s \in ServSet_o \\ s \neq SDLM2}} PdSet_{a,s} \bigcap_{s \in ServSet_o} OperSet_o \bigcap ASPA2Set_a & \forall a,o \mid \{SDLM2\} \subset ServSet_0 \end{Bmatrix}.$$

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IV. MODEL IMPLEMENTATION AND APPLICATIONS

This chapter discusses the implementation of DMAAP's ILP and the Excel interface. The chapter concludes with a description of four depot service-scheduling policies analyzed by this thesis.

A. MODEL IMPLEMENTATION

The General Algebraic Modeling System (GAMS), release 2.50A, provides the ILP implementation environment [Brooke et al. 1997]. SEMCOR Corporation provides all data required for the ILP [Tierney 2000]. The 29 August 2000 Master Plan provides the WCS and major modification kit delivery schedule data. Since the ILP formulation allows for repeated use, the model user must enter October of the fiscal year prior to the run date as the first period. The last period is fiscal year 2015, the planned retirement of the EA-6B. All model runs for this thesis use a planning horizon of October 2000 to September 2015, therefore October 1999 must be the first period. Fiscal year 2000 inductions provide a historical starting point, so $INDUCT_{a,o,p}$ for each aircraft inducted in periods one through 12 equals one, and all other $INDUCT_{a,o,p}$ variables in those periods equal zero. GAMS calls CPLEX 6.6 [ILOG 2000] to solve the ILP indexed with 124 aircraft, eligible for 35 possible options, over the 81 periods, generating approximately 78,000 constraint equations, 356,000 variables of which 303,000 are binary and 3,223,000 non-zero elements. Using a Pentium-III, 1-GHz, 1–GB computer, CPLEX provides solutions in less than 28 minutes with less than a one percent integrality gap. When we relax $AvailSet_{a,o}$ as described in chapter III.D, CPLEX requires up to three and a half hours to reach a solution.

Results are acquired from four scenarios representing four different scheduling policies that have been used by PMA-234. Policies 1, 2, 3 and 4 are partitioned into two groups (see Table 4). Policies 1 and 2 allow aircraft recommended for a WCS installation to receive a concurrent SDLM early as long as it has entered its ASPA inspection cycle. Policies 3 and 4 use the redefined version of $AvailSet_{a,o}$ described in chapter III.C in order to allow early SDLM if combined with any kit installation service

(WCS, 8289A, etc.). For example, under Policy 1 and 2 aircraft can be inducted for SDLM prior to the fifth ASPA only if they require a WCS within their respective ASPA cycle. Policies 3 or 4 allow early induction for SDLM if an aircraft is available for any major aircraft modification service during its ASPA cycle. Policies 3 and 4 allow for better SDLM induction level-loading, which in turn could reduce the bow-wave of SDLM inductions for refurbished aircraft in fiscal years 2005, 2006 and 2007.

Within both groups, the policies differ in how the installation of major modification kits is regulated. Policy 1 and 3 allow the ILP to recommend scheduled WCS and major modification kit installation services regardless of the kit delivery schedule. Placing no restriction on kit installation timing allows the model to suggest a modification management plan minimizing total aircraft out of service time, however this option tends to delay modified aircraft reaching the fleet. Policies 2 and 4 are restrictions of Policies 1 and 3 respectively requiring the installation of major modification kits during the fiscal year in which they are delivered. This equates to a policy of modifying aircraft with older systems as soon as possible. PMA-234 currently schedules depot maintenance services in accordance with Policy 4.

Depot Scheduling Policy Scenarios	
Group A (early SDLM only with WCS)	**Group B** (early SDLM with any modification)
Policy 1 (no restriction on kit installation)	**Policy 3** (no restriction on kit installation)
Policy 2 (install kits the year they are delivered)	**Policy 4** (install kits the year they are delivered)

Table 4. Depot Scheduling Policy Scenarios. Combinations of possible scheduling policies produce the four scenarios analyzed in this thesis. The analysis should determine the effects on the EA-6B inventory of using differing policies for scheduling depot maintenance services. For example, Policy 2 requires the installation of a major modification kit no later than the end of the year it is delivered and only allows SDLM services before the 5th ASPA if the recommended option includes a WCS installation.

B. DMAAP USER INTERFACE

DMAAP's Excel interface allows users unfamiliar with the GAMS modeling language to enter data for the ILP into an Excel workbook [Rutherford et al. 1999]. Known as the *Interface* the Excel workbook converts 5th ASPA due date, projected 95% FLE date and the current block configuration for each aircraft into the indexed sets implemented in the ILP (Table 5). The Interface also converts dates, where required for use by the ILP, into ordinal periods. User defined parameters such as the time required to complete an option or the WCS and major modification kit delivery schedule are entered into the interface without having to change GAMS code. The recommended Master Plan (Appendix A) and model data (Appendix B) is passed to the Interface when the solver obtains a solution. The GAMS-Excel Interface software is used to import the indexed sets and export model output.

Aircraft Buno	Wing Type	Block	ASPA 5 Date	Projected 95% FLE
156481	NT-7079	89	May-00	7/21/05
158029	NT-7050	89	Nov-03	2/27/11
158030	MT-7079	82	Nov-02	2/19/99
158032	MT-7079	82	Jul-01	1/31/10
158033	NT-7079	89	Jun-06	6/22/14
158034	NT-7079	82	Nov-05	3/22/14
158035	MT-7050	82	Mar-07	9/3/10
158036	MT-7075	82	Jul-00	1/4/09
158039	NT-7050	89	Aug-07	7/4/15
158040	NT-7079	82	Dec-04	3/1/11

Table 5. List of Aircraft Data. DMAAP's Excel interface allows users unfamiliar with the GAMS modeling language to enter ILP data into an Excel workbook. Known as the *Interface*, the Excel workbook converts a list of each aircraft's wing type, block configuration , 5th ASPA inspection due date and the projected date the WCS exceeds 95% FLE into the indexed sets required by the ILP.

C. DMAAP APPLICATIONS

DMAAP's main purpose is to provide a recommended induction schedule in the form of the current Master Plan. Monthly runs update the Master Plan to reflect changes to the aircraft inventory such as projected FLE dates and ASPA inspection failures. For

example, if an aircraft has been over utilized its corresponding 95 percent FLE date may move forward. Running the ILP with the new FLE date provides an updated Master Plan.

Regardless of the policy used, the ILP is formulated to provide the flexibility desired by PMA-234 planners. It can be used as a policy analysis tool as seen in the first section of Chapter V. It can also be used as planning tool to "what if" proposals such as the effects of Changing the delivery schedule of major modification kits as shown in the second part of chapter V. In all cases DMAAP recommends major modification kit delivery schedules for periods outside the FYDP.

V. POLICY ANALYSIS AND RESULTS

This chapter analyses the four scheduling policies introduced in Chapter IV. The chapter concludes with a comparison of major aircraft modification kit delivery schedules, highlighting DMAAP's capability as a planning tool.

A. POLICY ANALYSIS USING DMAAP

Initial model testing compared the impact of completing 8289A services by the end of fiscal year 2004 as currently planned, against allowing all modification services until 2010. Removing block 82 aircraft as quickly as possible requires nine additional inductions but only increases total depot maintenance time by 28 months, less than a 1 percent increase. Due to the operational and maintenance burdens placed on squadrons by block 82 aircraft, and the minimal consequences of completing all 8289A services by 2004, all model results reflect completion of all 8289A services by 2004.

Recall Group A (Policies 1 and 2) allows SDLM before the fifth ASPA due date only if it can be fitted with a WCS within its ASPA period. Policy 1 places no restrictions on when major modification kits can be installed, kits delivered this year can be held for installation in future years. Policy 2 is a restriction of Policy 1 requiring installation of major modification kits in the year they are delivered. Both policies allow recommended installations in numbers greater than the number of projected kit deliveries. This is the means by which the ILP suggests additional component procurement required to modify all aircraft to ICAP-III prior to 2010. We expect the results from Policy 2 to be worse than Policy 1 as Policy 2 is a restriction of Policy 1. Table 6 highlights the increase in required depot work and decrease in PAI levels if program managers are required to use a policy similar to Policy 2 (see Table 6 and Figures 6 and 7).

Group A	Total Time (months)	Total Inductions (aircraft)	Average Yearly Inductions	Average PAI (aircraft)	%Time below PAA	Average Aircraft Shortfall
Policy 1	2889	269	19.2	105.9	32.9%	2.8
Policy 2	2950	280	20	105.0	39.7%	4.2

Table 6. Comparison of Policy 1 and 2. Group A allows SDLM before the fifth ASPA date only if it can be combined with a WCS within the aircraft's ASPA cycle. Policy 1 places no restrictions on when WCS and major modification kits can be installed while Policy 2 restricts kit installation to the fiscal year in which it is delivered. As expected, Policy 2 increases total time in months required to perform all recommended options. Total inductions represents the number of times aircraft are inducted over the planning horizon, several aircraft are inducted multiple times. This number divided by 14 provides average yearly inductions. Average PAI represents the long run PAI average, but the amount of time that PAI is below PAA is our main concern. A 39.7% time below PAA represents the percentage of periods we can expect to have less than 104 operational aircraft and the average aircraft shortfall represents on average how many aircraft below PAA.

Analyzing the two policies shows Policy 2 increases total maintenance time 61 months or 2.1 percent and total inductions by 11 or 4.1 percent in relation to Policy 1. This equates to about a half year of additional depot work. More importantly, Policy 2 increases the amount of time aircraft are removed from PAI. Policy 1 provides higher PAI levels in all periods except 2010. Figure 6 indicates Policy 2 slightly improves the level loading of inductions for depot services and leveling the yearly maintenance time required to complete those services. Note, Policy 2 (and 4) forces the recommended induction schedule to install major modification kits in the year they are delivered. The recommended solution is directly influenced by the kit delivery schedule used in the ILP and may improve or worsen in comparison with Policy 1 if the delivery schedule is changed. In this comparison Policy 2 decreases overall PAI levels in order to acquire ten additional block-89A aircraft in fiscal year 2001, about three years earlier than under Policy 1. Ten airplanes would equip two EA-6B squadrons, OPNAV aircraft inventory managers would have to gauge the utility of having two additional squadrons of block

89A aircraft three years early against an overall decrease in aircraft available to fleet commanders.

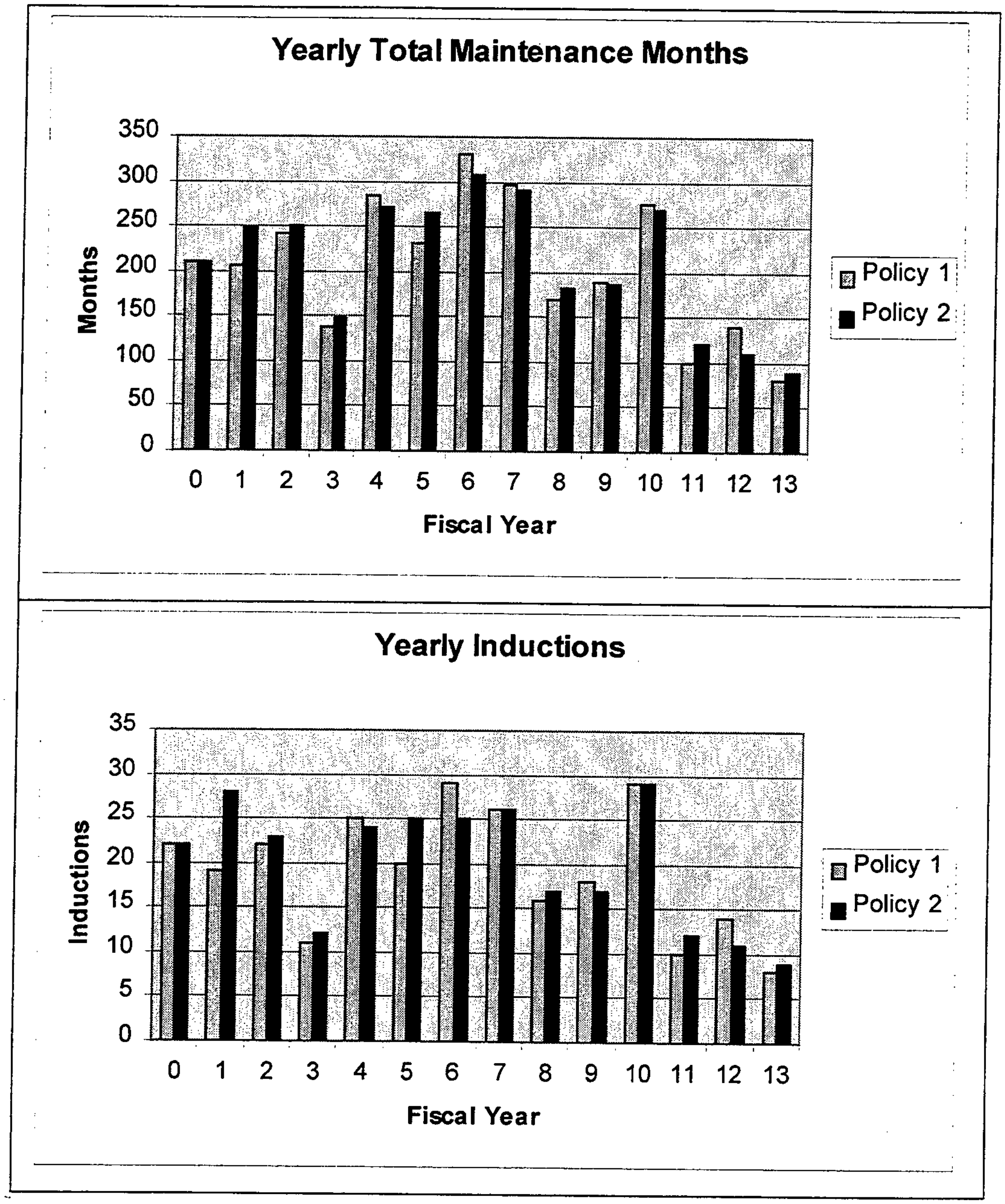

Figure 6. Comparison of Group A Yearly Total Maintenance Months and Inductions. The charts show Policy 2 is slightly better at leveling yearly workloads and induction numbers. However, aircraft inventory levels are worse for Policy 2.

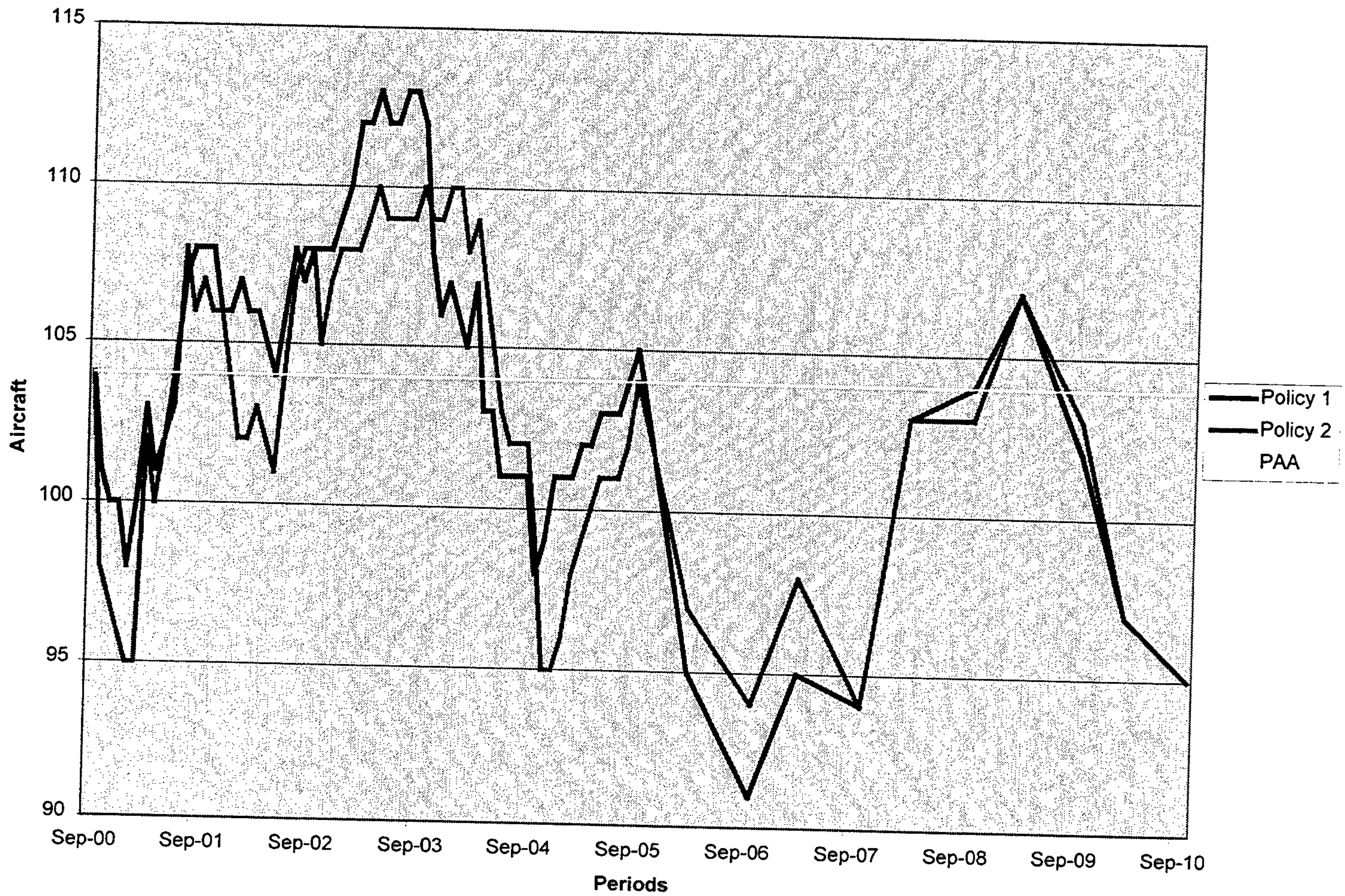

Figure 7. Comparison of Group A PAI levels against PAA. This chart compares Policy 1 and 2's PAI levels for each period in relation to a 104 PAA. Policy 1's average PAI is 105.9 aircraft with PAI falling below PAA 32 percent of the time and an average PAI shortfall of 2.8 aircraft. Policy 2's average PAI is 105 aircraft, PAI falls below PAA 39.7 percent of the time and a average PAI shortfall of 4.2 aircraft.

As expected comparing Policies 3 and 4 (Group B) reveals the same trends seen in the Policy 1 and 2 (Group A) analysis, however Group B completes services a year earlier than the policies of Group A. This earlier completion of services comes with a high cost in terms of aircraft availability; Policy 3's PAI level is below PAA 52 percent of the time and Policy 4's is 57 percent. As shown previously, restricting modification kit installation periods increases total maintenance time and inductions while decreasing PAI levels.

Comparing similar polices between the groups reveals the possible effects of allowing early SDLM when combined with any other depot service. Both Policy 1 and 3 place no restrictions on major aircraft modification kit installation, however Policy 3 allows early SDLM if combined with any other service while Policy 1 only allows early SDLM if combined with WCS. Table 7 and Figures 8 and 9 show that Policy 3 decreases total maintenance time by 3.1 percent, the required number of inductions by 6.7 percent and does a better job of level loading yearly depot work. Policy 3 finishes the required work by fiscal year 2012. This would seem to be the obvious policy, however inventory managers must again weigh level depot workloads against operational requirements. The benefits of Policy 3 are gained by reducing PAI levels throughout the planning horizon. Figure 9 shows that Policy 3's PAI falls below PAA 20 percent more often than Policy 1 and the magnitude of the shortfalls is greater with the exception of years 2005 and 2006. This is because in order to make up for lighter inductions in the early years using Policy 1, the ILP must recommend a larger number of options containing more than two services thus keeping aircraft out of PAI for longer periods.

In either case DMAAP provides a recommended kit installation schedule for years outside the FYDP. The variable $NOKITS_{s,y}$ provides the WCS and major modification kit levels required to support the recommended schedule. This recommended kit delivery schedule could then be programmed in the FYDP and implemented into DMAAP under Policy 2 or 4 to provide the Master Plan.

Between Groups	Total Time (months)	Total Inductions (aircraft)	Average Yearly Inductions	Average PAI (aircraft)	%Time below PAA	Average Aircraft Shortfall
Policy 1	2889	269	19.2	105.9	32.9%	2.8
Policy 3	2799	251	19.3	104.3	52.1%	4.0

Table 7. Policy 1 and 3 Results. Both Policy 1 and 3 place no restriction on major modification kit installation. Policy 1 allows SDLM before the fifth ASPA date only if it can be combined with WCS within its ASPA period. Policy 3 allows early SDLM with any major modification service. In this comparison Policy 3 reduces total maintenance time by 3.1% and total inductions by 6.75% but at a cost of increasing time PAI falls below PAA by 20%.

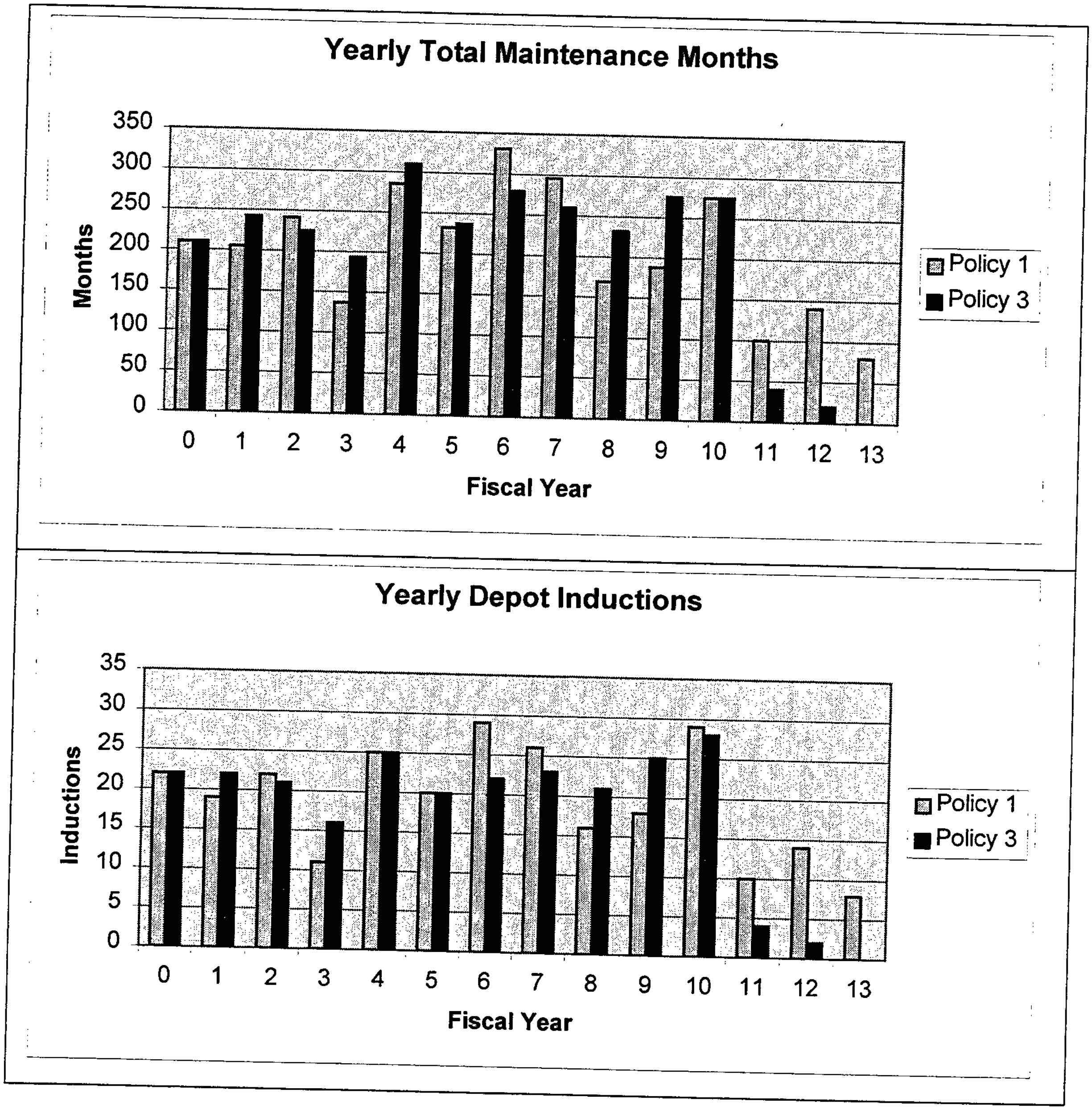

Figure 8. Comparison of Policy 1 and 3's Yearly Total Maintenance Months and Inductions. Both charts show Policy 3 moves depot services forward and therefore is better at level loading the depots.

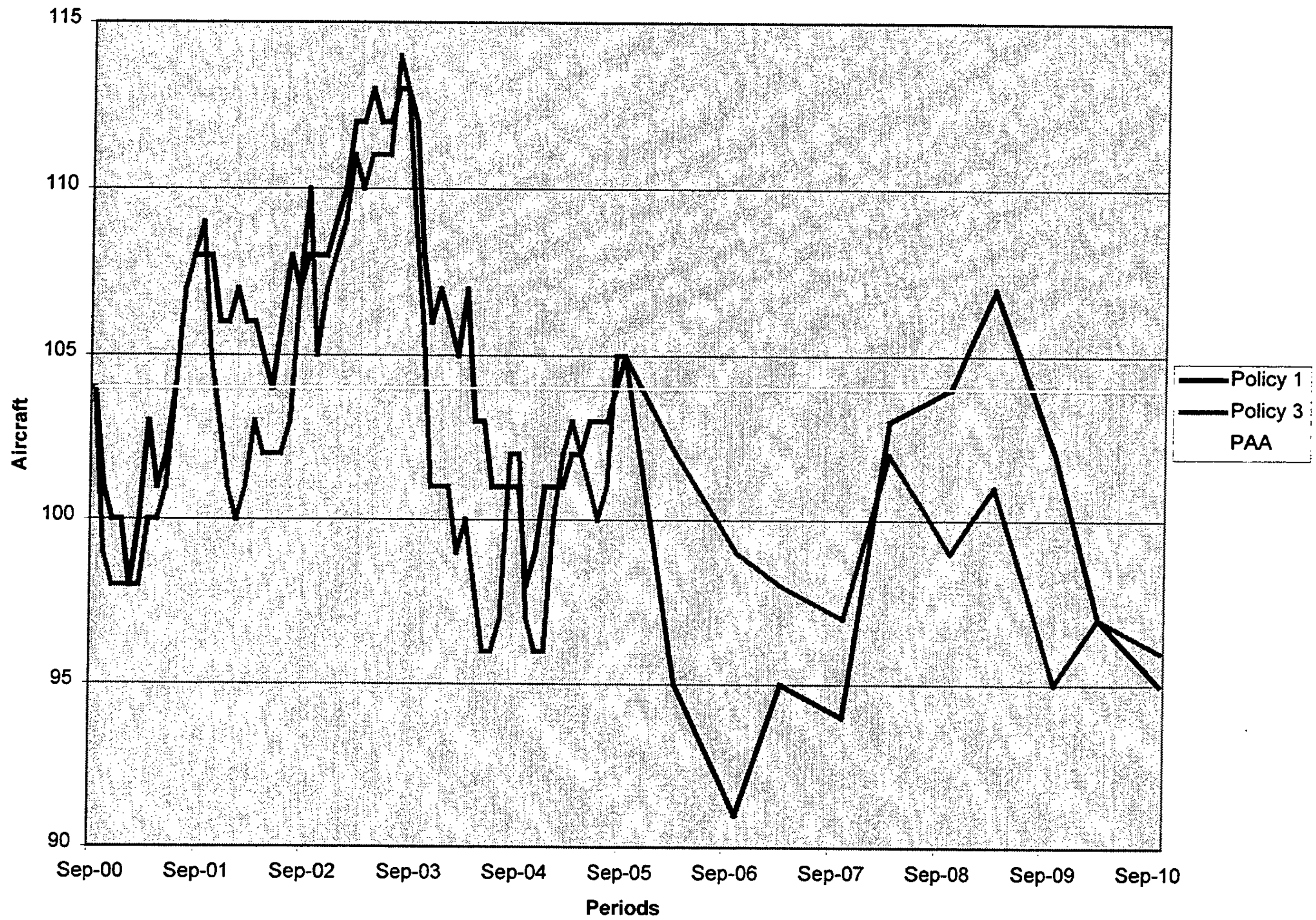

Figure 9. Comparison of Policy 1 and 3's PAI levels against PAA. This chart compares Policy 1 and 3's PAI levels for each period in relation to a 104 PAA. Policy 1's average PAI is 105.9 aircraft with PAI falling below PAA 32 percent of the time and an average PAI shortfall of 2.8 aircraft. Policy 3's average PAI is 104.3 aircraft, PAI falls below PAA 52.1 percent of the time and a average PAI shortfall of 4 aircraft. Policy 3 completes more services earlier in the planning horizon and reduces the PAI shortfall in the bow wave years 2006 and 2007. However, EA-6B tasking is currently (2000) high and the fleet may not be able to shoulder a 20% increase in PAI shortfalls.

B. KIT DELIVERY PLANNING

We now show an example of using DMAAP as a planning tool not only to schedule depot maintenance but to also help plan WCS and major modification kit delivery schedules. Here we have hypothetically selected depot scheduling Policy 2 requiring installation of modification kits the same year they are delivered. We make two runs with input data reflecting two WCS and major modification kits delivery schedules. Policy 2 enforces the installation of the kits in the year delivered, but the ILP will recommend scheduling for any remaining modification kit shortfall in each plan. The August 2000 Master Plan provides the delivery schedule for the first run ("Aug plan"). The second run data is a plan proposed by PMA-234 in September 2000 ("Sep plan") [Tierney 2000]. The Sep plan increases 8289A and 89A modification kit shortfalls in the early years and reduces the initial number of ICAP-III modification kits.

Side by side comparison shows little difference between the two plans for total maintenance months and inductions and a slight improvement in PAI levels for the Sep plan (see Table 8). The amount of time PAI levels fail to reach PAA for the Sep plan drops to 35.6 percent while average aircraft shortfall holds steady at four (see Figure 10). Inspecting PAI levels in Figure 10 we see the Sep plan moves services forward into 2004 without having a detrimental effect as PAI levels generally stay above PAA. The Sep plan also provides smaller PAI shortfalls during the SDLM laden years, 2006 and 2007. The results tell the user it is advisable to use the Sep plan for FYDP planning and programming.

Kit Delivery Schedules	Total Time (months)	Total Inductions (aircraft)	Average Yearly Inductions	Average PAI (aircraft)	%Time below PAA	Average Aircraft Shortfall
Aug plan	2950	280	20.2	105.0	39.7%	4.2
Sep plan	2959	284	20.3	104.6	35.6%	4.0

Table 8. Comparing Modification Kit Delivery Schedules. Here we use Policy 2, requiring WCS and major modification kit installation in the year it is delivered, to

compare proposed kit delivery schedules. The Aug plan is from the August 2000 Master Plan, and the Sep plan is a proposed change for the September 2000 Master Plan. The Sep plan decreases PAI shortfalls and should be used in place of the Aug plan.

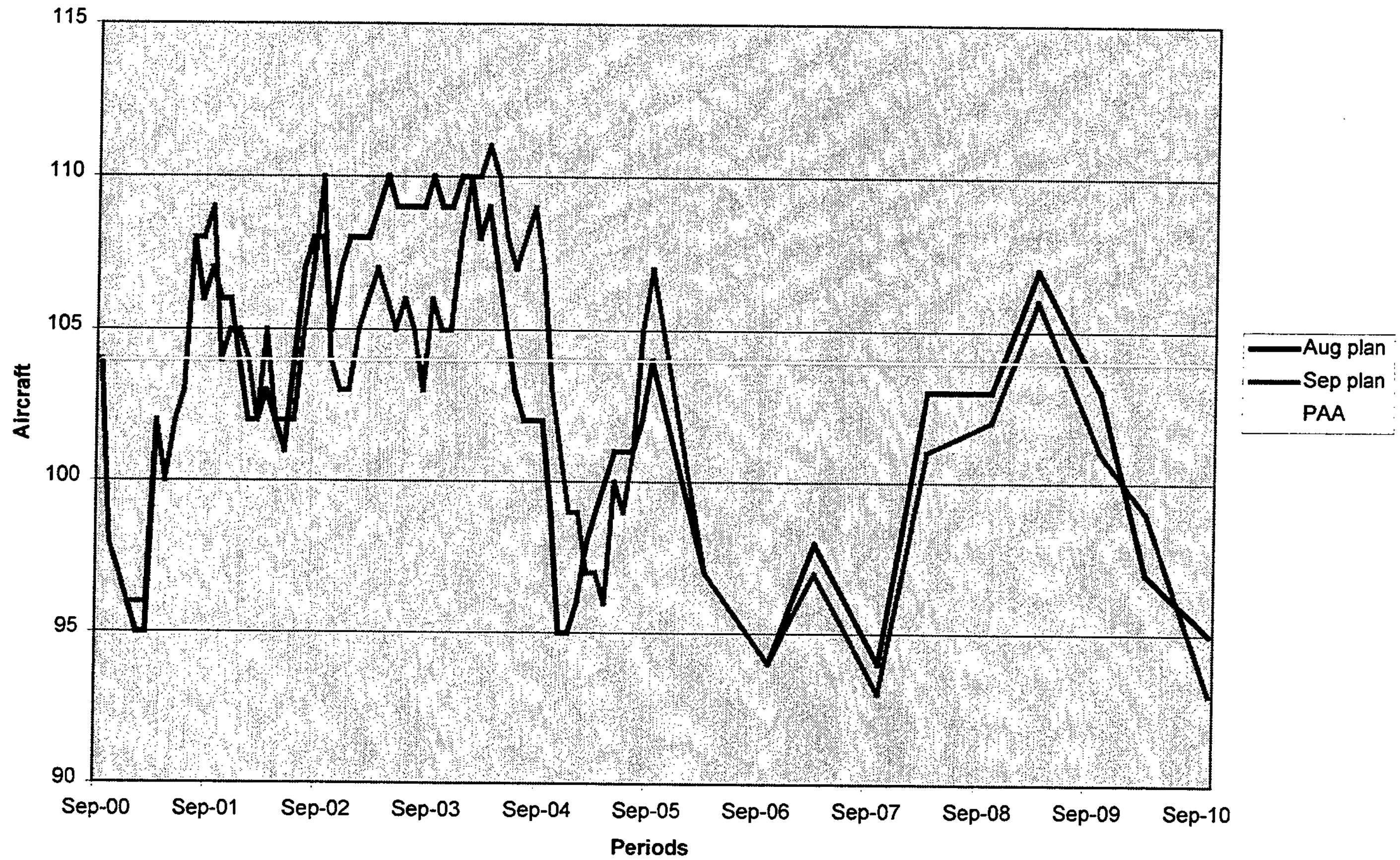

Figure 10. Comparison of PAI for Two Modification Kit Delivery Schedules. This chart compares the old, August 2000, modification kit delivery schedule against the newly proposed September 2000 plan. The Aug plan's PAI falls below PAA 39.7% of the time while the Sep plan falls below 35.6% of the time. The graph also shows that while more aircraft are removed from PAI in fiscal year 2004 PAI levels are still acceptable and less aircraft are removed from PAI during 2006 and 2007. These results recommend adopting the Sep plan.

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VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

This thesis introduces DMAAP, a prototypic decision support tool capable of rapidly providing a Master Plan for scheduling EA-6B depot level maintenance services. DMAAP's recommended Master Plan schedules all required SDLM and completes all major aircraft modification services while minimizing the number of aircraft removed from PAI. The ease with which differing scheduling policies can be enforced demonstrates DMAAP's flexibility as a planning tool. Implementing DMAAP with the scheduling policy required by PMA-234 provides the means to develop a WSC and major modification kit management plan. If no WCS and major modification kit deliveries are input, the ILP delivers a basic modification management plan. If the current FYDP kit delivery schedule is input the results indicate where kit shortfalls can be made up while again completing all services. Finally, DMAAP can be used to compare the value of a proposed change to the current FYDP schedule.

DMAAP is easily transferable for use under the IMC concept. Minor changes to the service set and available set allows the ILP to recommend WCS and remaining major modification kit installations in conjunction with IMC Phases. IMC Phase 8 would replace SDLM 1 and 2.

B. RECOMMENDATIONS

Today the EA-6B remains one of the oldest yet most sought after aircraft in the Department of Defense inventory. Its required presence in every contingency worldwide requires the most up to date electronic warfare aircraft possible. With no replacement aircraft due to arrive in the next ten years, it is imperative that the EA-6B fleet by kept on the cutting edge with the installation of WCS, where needed, and currently developed major aircraft modification kits. Getting these modifications on all EA-6B aircraft in a timely manner with little impact to the highly tasked fleet is a major concern. By adopting DMAAP to produce a depot level maintenance service Master Plan, PMA-234

acquires the capability to effectively plan and manage the services required to keep the only tactical electronic warfare aircraft on the cutting edge.

The following areas lend themselves to further the work in this thesis.

- Adapt DMAAP to the IMC program once the transition requirements have been established.

- Enhance the user interface for ease of data input and for executing GAMS directly from Excel.

APPENDIX A. DMAAP'S MASTER PLAN

Table 9 and 10 depict DMAAP's recommended EA-6B induction schedule for fiscal year 2000 to 2006 using Policy 4 (see Table 4) and the September 2000 major aircraft modification delivery schedule.

	Y00	Y01	Y02	Y03
SDLM1 SDLM2 WCS 8289A 89A ICAPIII	0 0 1 6 10 1	0 0 4 12 12 1	0 0 11 14 4 0	0 0 10 10 4 0
SDLM1	156481 Mar-00 OP1 158036 Jul-00 OP8 158039 Nov-99 OP1 160434 Dec-99 OP1 161242 Nov-99 OP1 161774 Sep-00 OP21 161775 May-00 OP1 161882 Apr-00 OP8 163526 May-00 OP9 163887 Mar-00 OP9 163888 Feb-00 OP9 163889 Feb-00 OP9 163891 Mar-00 OP9	158030 Mar-01 OP7 158801 Dec-00 OP1 159583 Aug-01 OP8 159585 Jul-01 OP8 160432 Feb-01 OP8 160709 May-01 OP20 161245 Aug-01 OP1 161347 Feb-01 OP21 161779 Nov-00 OP1 161881 Aug-01 OP8 162934 Sep-01 OP8 162939 Mar-01 OP7 163031 Dec-00 OP7 163033 Nov-00 OP8 163047 Jul-01 OP8 163530 Nov-00 OP9 163892 Jan-01 OP1 164403 Mar-01 OP1	158032 Oct-01 OP1 158040 Nov-01 OP8 158542 Oct-01 OP20 158802 May-02 OP8 160437 Oct-01 OP8 160787 Jun-02 OP8 161118 Oct-01 OP9 161352 Feb-02 OP21 161884 Aug-02 OP8 162230 Feb-02 OP8 162938 Oct-01 OP1 163034 Oct-01 OP8 163045 Dec-01 OP8 163048 Oct-01 OP8 163406 May-02 OP1 163884 Oct-01 OP1	158035 Jan-03 OP8 158804 May-03 OP8 159584 Jan-03 OP8 159909 Aug-03 OP1 159911 Aug-03 OP7 159912 Dec-02 OP8 160786 Sep-03 OP1 161348 Sep-03 OP20 161350 Mar-03 OP7 161885 Jul-03 OP20 162224 Aug-03 OP7 162228 Jul-03 OP7 163032 Oct-02 OP20 163400 Oct-02 OP21 163402 Mar-03 OP9 163529 Nov-02 OP1
SDLM2				
WCS	161774 Sep-00 OP21	158030 Mar-01 OP7 160709 May-01 OP20 161116 Jan-01 OP16 161347 Feb-01 OP21 162939 Mar-01 OP7 163031 Dec-00 OP7	156481 Nov-01 OP3 158542 Oct-01 OP20 160787 Jun-02 OP3 161243 Apr-02 OP16 161244 Apr-02 OP3 161352 Feb-02 OP21 162938 Jun-02 OP15 163525 Jan-02 OP16	159911 Aug-03 OP7 161242 Oct-02 OP16 161348 Sep-03 OP20 161349 Nov-02 OP15 161350 Mar-03 OP7 161779 Sep-03 OP15 161885 Jul-03 OP20 162224 Aug-03 OP7 162228 Jul-03 OP7 163032 Oct-02 OP20 163400 Oct-02 OP21
8289A	158036 Jul-00 OP8 160436 Aug-00 OP4 161882 Apr-00 OP8 162224 Sep-00 OP4 162228 Sep-00 OP4 162936 Sep-00 OP4	158650 Oct-00 OP4 158801 Nov-00 OP4 159583 Aug-01 OP8 159585 Jul-01 OP8 160432 Feb-01 OP8 160709 May-01 OP20 160786 Dec-00 OP4 161881 Aug-01 OP8 162934 Sep-01 OP8 163033 Nov-00 OP8 163046 Oct-00 OP4 163047 Jul-01 OP8	158034 Feb-02 OP4 158040 Nov-01 OP8 158542 Oct-01 OP20 158802 May-02 OP8 158805 Dec-01 OP4 160437 Oct-01 OP8 160609 Nov-01 OP4 160787 Jun-02 OP8 161884 Aug-02 OP8 162230 Feb-02 OP8 162938 Jun-02 OP15 163034 Oct-01 OP8 163045 Dec-01 OP8 163048 Oct-01 OP8	158035 Jan-03 OP8 158804 May-03 OP8 159584 Jan-03 OP8 159912 Dec-02 OP8 161245 Sep-03 OP18 161348 Sep-03 OP20 161349 Nov-02 OP15 161779 Sep-03 OP15 161885 Jul-03 OP20 163032 Oct-02 OP20
89A	161774 Sep-00 OP21 162227 Sep-00 OP5 163395 Jul-00 OP5 163521 Jun-00 OP5	158807 Oct-00 OP5 158816 Feb-01 OP5 159907 Jun-01 OP5 159911 Apr-01 OP5	161118 Oct-01 OP9 161243 Apr-02 OP16 161352 Feb-02 OP21 163525 Jan-02 OP16	161242 Oct-02 OP16 161775 Mar-03 OP5 163400 Oct-02 OP21 163402 Mar-03 OP9

Table 9. DMAAP's Fiscal Year 2000 Master Plan (page 1).

Y04	Y05	Y06
0 0 10 5 0 12	0 0 10 0 14 12	0 0 10 0 16 16
158029 Oct-03 OP1 158540 Oct-03 OP1 158816 Apr-04 OP10 160436 Oct-03 OP1 160609 Aug-04 OP10 161116 Jan-04 OP10 161349 Oct-03 OP10 161883 Nov-03 OP8 162227 Oct-03 OP10 162936 May-04 OP7 163046 Nov-03 OP22 163049 Oct-03 OP1 163395 Dec-03 OP22 163523 Apr-04 OP22 163890 Oct-03 OP1	158033 Apr-05 OP24 158649 Apr-05 OP24 158800 Feb-05 OP24 159586 Oct-04 OP24 160707 Feb-05 OP24 160791 Dec-04 OP24 161115 Oct-04 OP33 161120 Oct-04 OP1 161880 Jun-05 OP24 163398 Oct-04 OP33 163401 Oct-04 OP33 163403 Nov-04 OP9 163521 Oct-04 OP1 163524 Dec-04 OP33 163528 Jun-05 OP33 164402 Oct-04 OP1	158034 FY06 OP10 158650 FY06 OP10 158805 FY06 OP10 160433 FY06 OP24 160788 FY06 OP24 161119 FY06 OP33 161243 FY06 OP10 161244 FY06 OP24 162935 FY06 OP24 163030 FY06 OP24 163035 FY06 OP24 163396 FY06 OP24 163397 FY06 OP33 163399 FY06 OP33 163404 FY06 OP9 163520 FY06 OP33 163522 FY06 OP33 163527 FY06 OP33 164401 FY06 OP24
		158030 FY06 OP14 163045 FY06 OP2
161882 Oct-03 OP3 162936 May-04 OP7 163033 Feb-04 OP17 163045 Feb-04 OP17 163046 Nov-03 OP22 163395 Dec-03 OP22 163523 Apr-04 OP22 163887 Oct-03 OP3	161115 Oct-04 OP33 161245 Oct-04 OP3 163398 Oct-04 OP33 163401 Oct-04 OP33 163524 Dec-04 OP33 163528 Jun-05 OP33	161119 FY06 OP33 162230 FY06 OP17 163397 FY06 OP33 163399 FY06 OP33 163520 FY06 OP33 163522 FY06 OP33 163527 FY06 OP33 163884 FY06 OP16
158030 Dec-03 OP4 158032 Aug-04 OP4 161883 Nov-03 OP8 162939 Mar-04 OP4 163031 Jun-04 OP18		
	158033 Apr-05 OP24 158649 Apr-05 OP24 158800 Feb-05 OP24 159586 Oct-04 OP24	160433 FY06 OP24 160788 FY06 OP24 161119 FY06 OP33 161244 FY06 OP24

Table 10. DMAAP's Fiscal Year 2000 Master Plan (page 2).

APPENDIX B. ILP OUTPUT

The ILP provides statistics to help compare scheduling policies and proposed major aircraft modification kit delivery schedules. The GAMS-Excel Interface software passes GAMS variable and parameter values to the Excel Interface Results worksheet.

This worksheet presents the statistics accosiated with the last run of DMAAP's ILP

Objective Function Value
646615.2

Total Inductions
273

Total Time to Complete All Services (months)
2915

Recommended Additional WCS Delivery Schedule (cumulative # of additional WCS)

Y00	Y01	Y02	Y03	Y04	Y05	Y06	Y07	Y08
2	1							

Recommended Additional Modification Kit Delivery Schedule (cumulative # of kits)

	Y00	Y01	Y02	Y03	Y04	Y05	Y06	Y07
8289A								
89A								
ICAPIII				1			4	8

Yearly Total Maintenance Work (months)

Y00	Y01	Y02	Y03	Y04	Y05	Y06	Y07	Y08	Y09	Y10	Y11
210	307	275	238	252	218	290	305	192	266	272	30

Total Yearly Aircraft Inductions (# of aircraft inducted)

Y00	Y01	Y02	Y03	Y04	Y05	Y06	Y07	Y08	Y09	Y10	Y11
22	33	25	21	23	18	23	29	16	24	30	3

Yearly SDLM1 Inductions (# of aircraft inducted for SDLM1)

Y00	Y01	Y02	Y03	Y04	Y05	Y06	Y07	Y08	Y09	Y10	Y11
13	18	16	16	15	16	19	11				

Yearly SDLM2 Inductions (# of aircraft inducted for SDLM2)

Y00	Y01	Y02	Y03	Y04	Y05	Y06	Y07	Y08	Y09	Y10	Y11
						2	10	15	13	15	1

Number of PAI Aircraft per Period (# of aircraft not inducted in each period)

Oct-99	Nov-99	Dec-99	Jan-00	Feb-00	Mar-00	Apr-00	May-00	Jun-00	Jul-00	Aug-00	Sep-00
124	122	121	121	119	116	115	113	112	110	108	104

Figure 11. Portion of the DMAAP Interface Results Excel Worksheet.

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